US009148867B2

(12) **United States Patent**
Nakata et al.

(10) **Patent No.: US 9,148,867 B2**
(45) **Date of Patent: Sep. 29, 2015**

(54) **WIRELESS COMMUNICATION APPARATUS AND WIRELESS POSITIONING SYSTEM**

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(72) Inventors: **Tsuneo Nakata**, Kariya (JP); **Shigeki Kawai**, Nagoya (JP)

(73) Assignee: **DENSO CORPORATION**, Kariya (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 122 days.

(21) Appl. No.: **13/896,620**

(22) Filed: **May 17, 2013**

(65) **Prior Publication Data**

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(30) **Foreign Application Priority Data**

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Feb. 14, 2013 (JP) 2013-026586

(51) **Int. Cl.**

H04W 24/00	(2009.01)
H04W 64/00	(2009.01)
G01S 7/00	(2006.01)
G01S 11/06	(2006.01)
G01S 13/93	(2006.01)
G08G 1/01	(2006.01)

(52) **U.S. Cl.**

CPC ***H04W 64/00*** (2013.01); ***G01S 7/003*** (2013.01); ***G01S 11/06*** (2013.01); ***G01S 13/931*** (2013.01); ***G08G 1/0112*** (2013.01); ***G08G 1/0133*** (2013.01); *G01S 2013/936* (2013.01)

(58) **Field of Classification Search**

CPC H04W 64/00; H04W 64/003
USPC 455/456.1, 450, 457, 418–422.1, 436; 370/328, 338, 331

See application file for complete search history.

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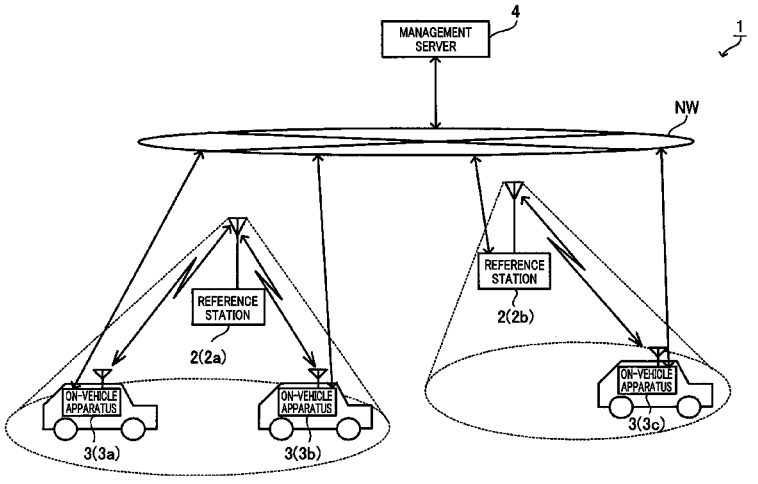
(57) **ABSTRACT**

In a wireless communication apparatus, data transmitted from at least one wireless transmitter is received by direct wireless communication, and its wireless reception condition is detected. Relation reference information setting two or more relations between the wireless reception condition on a reception of transmitted data and location information of the transmitter is stored. Relative distance information of a relative distance between the transmitter and the apparatus is measured. Relation information indicating a relation between the wireless reception conditions and the relative distance information is generated. A relation between the location information and the relative distance information is determined by comparing the relation reference information and the relation information. A current location of the apparatus is determined on the basis of the relation between the location information and the relative distance information and a current wireless reception condition.

20 Claims, 29 Drawing Sheets



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* cited by examiner

FIG. 1

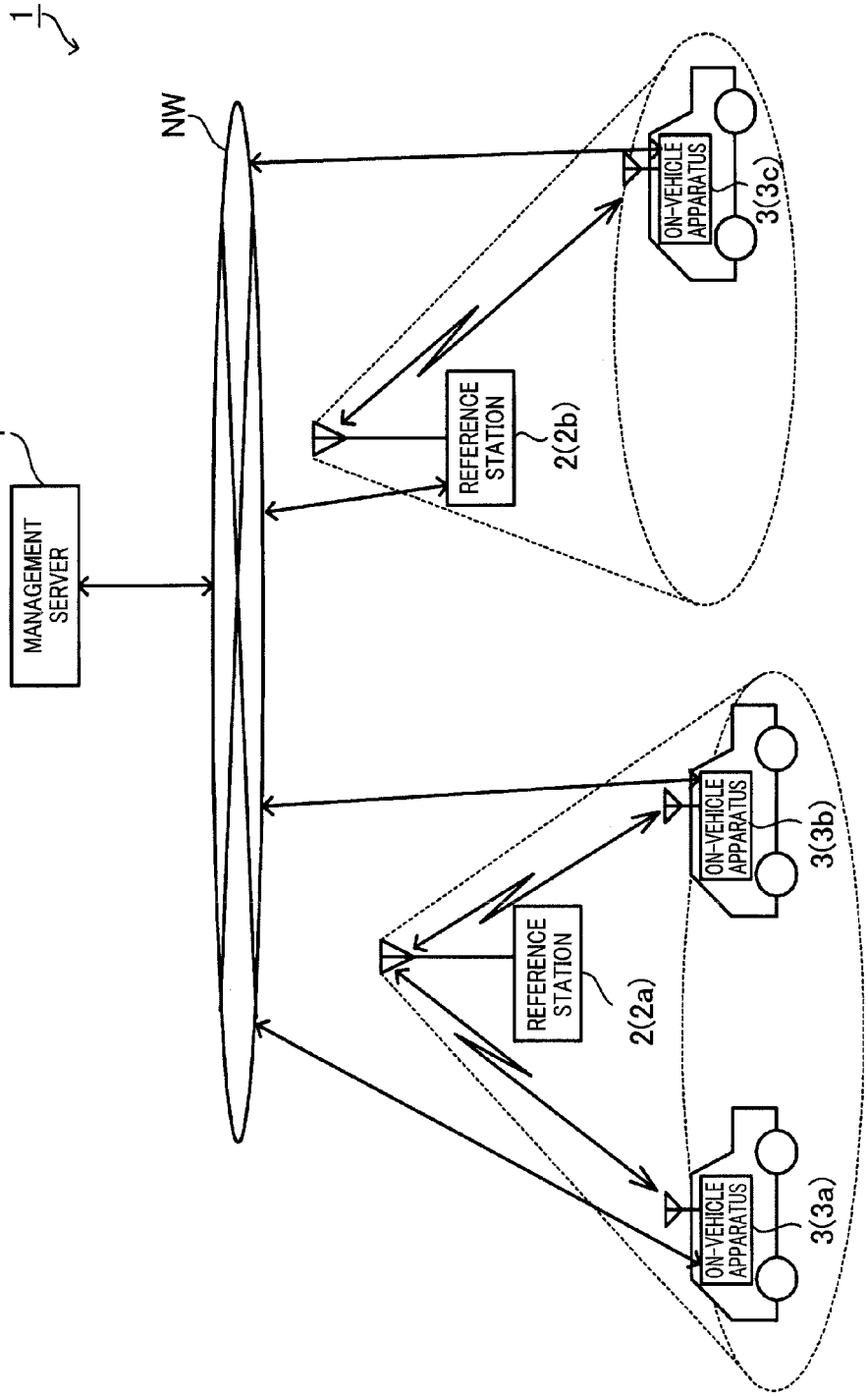

1
NW
4
MANAGEMENT SERVER
REFERENCE STATION
2(2b)
ON-VEHICLE APPARATUS
3(3c)
REFERENCE STATION
2(2a)
ON-VEHICLE APPARATUS
3(3b)
ON-VEHICLE APPARATUS
3(3a)

FIG.2

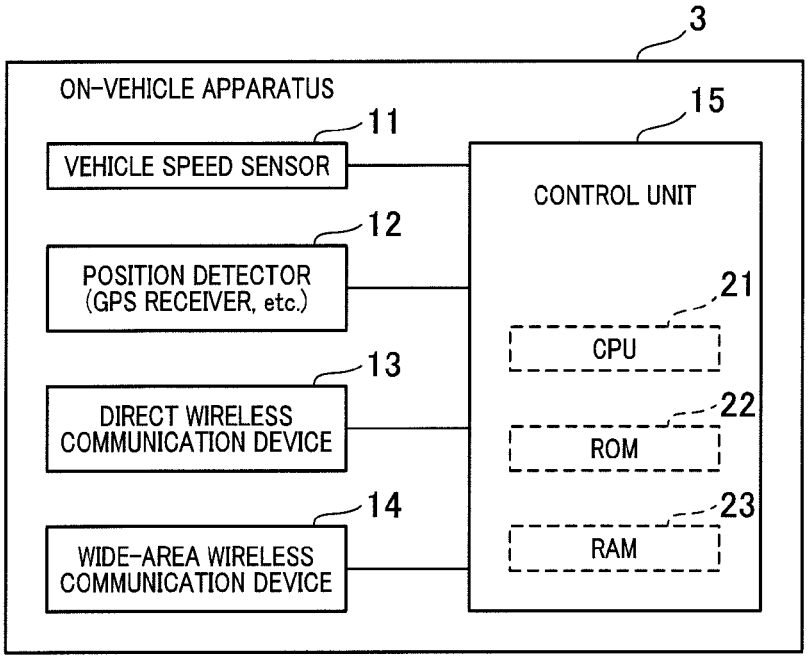

3
ON-VEHICLE APPARATUS
11
VEHICLE SPEED SENSOR
12
POSITION DETECTOR
(GPS RECEIVER, etc.)
13
DIRECT WIRELESS
COMMUNICATION DEVICE
14
WIDE-AREA WIRELESS
COMMUNICATION DEVICE
15
CONTROL UNIT
21
CPU
22
ROM
23
RAM

FIG.3

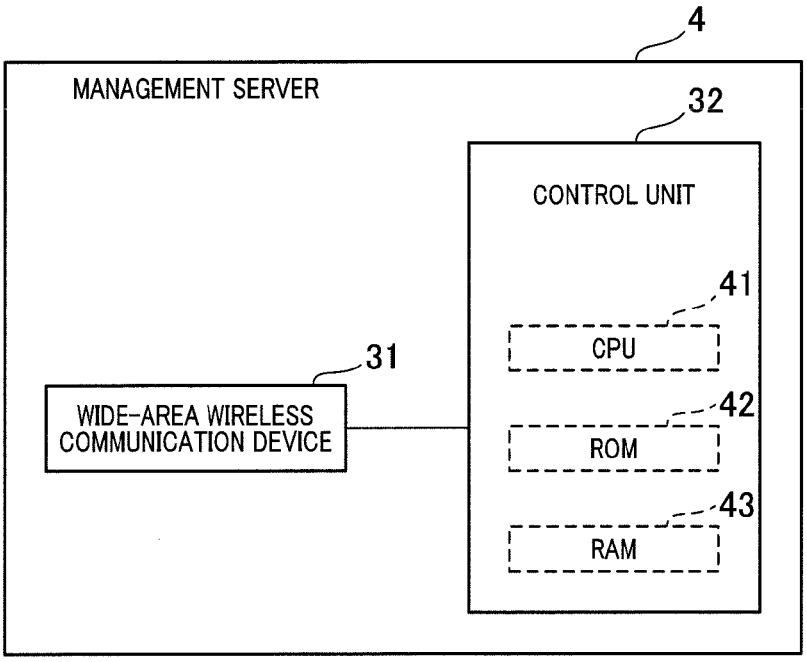

4
MANAGEMENT SERVER
31
WIDE-AREA WIRELESS
COMMUNICATION DEVICE
32
CONTROL UNIT
41
CPU
42
ROM
43
RAM

FIG.4

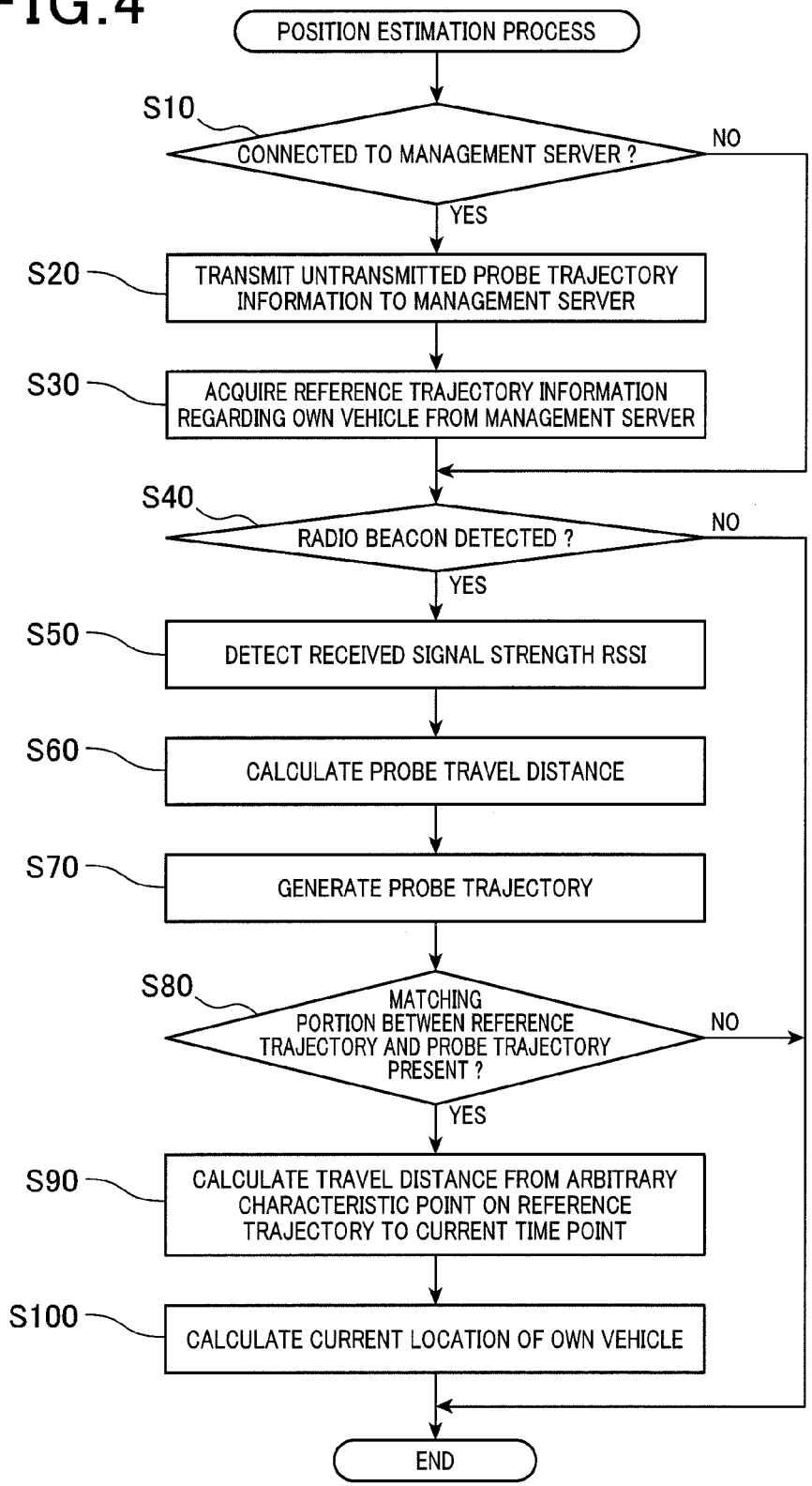

POSITION ESTIMATION PROCESS
S10
CONNECTED TO MANAGEMENT SERVER ?
NO
YES
S20
TRANSMIT UNTRANSMITTED PROBE TRAJECTORY INFORMATION TO MANAGEMENT SERVER
S30
ACQUIRE REFERENCE TRAJECTORY INFORMATION REGARDING OWN VEHICLE FROM MANAGEMENT SERVER
S40
RADIO BEACON DETECTED ?
NO
YES
S50
DETECT RECEIVED SIGNAL STRENGTH RSSI
S60
CALCULATE PROBE TRAVEL DISTANCE
S70
GENERATE PROBE TRAJECTORY
S80
MATCHING PORTION BETWEEN REFERENCE TRAJECTORY AND PROBE TRAJECTORY PRESENT ?
NO
YES
S90
CALCULATE TRAVEL DISTANCE FROM ARBITRARY CHARACTERISTIC POINT ON REFERENCE TRAJECTORY TO CURRENT TIME POINT
S100
CALCULATE CURRENT LOCATION OF OWN VEHICLE
END

FIG.5

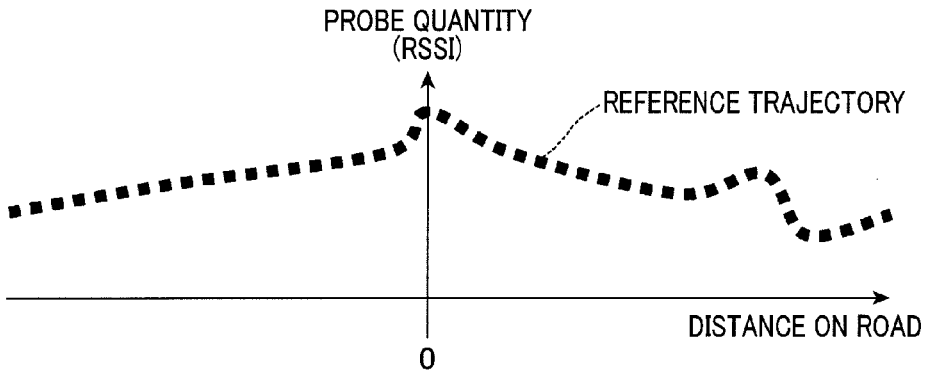

PROBE QUANTITY
(RSSI)
REFERENCE TRAJECTORY
DISTANCE ON ROAD
0

FIG.6

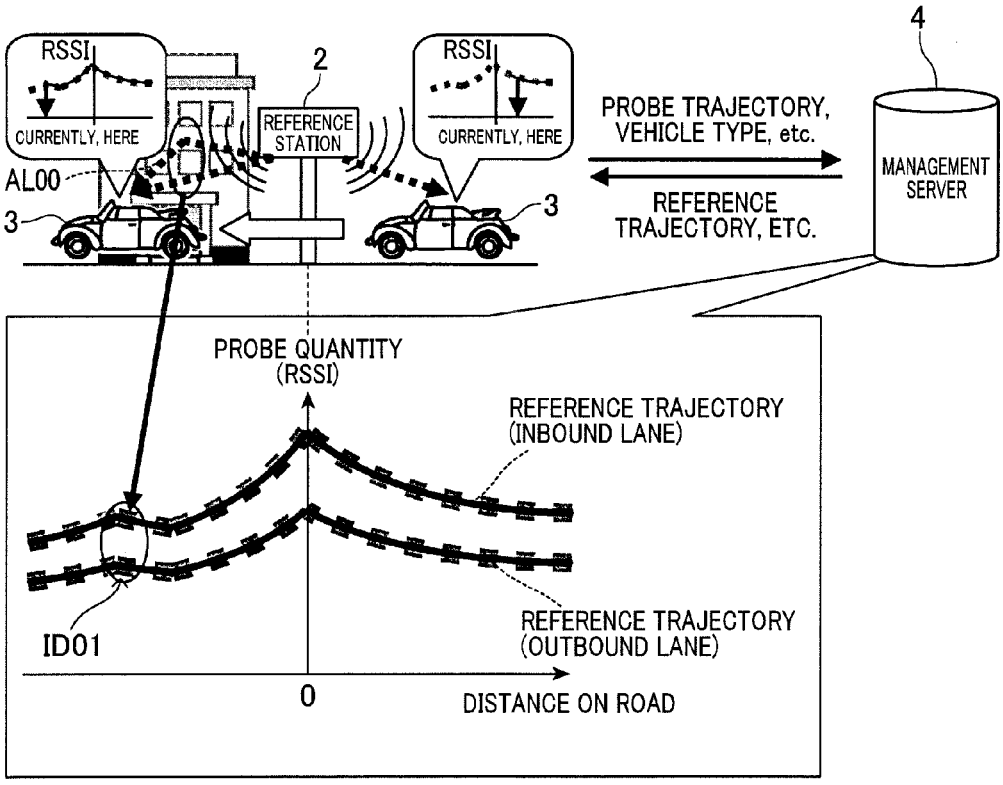

RSSI
CURRENTLY, HERE
2
REFERENCE STATION
RSSI
CURRENTLY, HERE
4
PROBE TRAJECTORY, VEHICLE TYPE, etc.
REFERENCE TRAJECTORY, ETC.
MANAGEMENT SERVER
AL00
3
3
PROBE QUANTITY
(RSSI)
REFERENCE TRAJECTORY
(INBOUND LANE)
REFERENCE TRAJECTORY
(OUTBOUND LANE)
ID01
0
DISTANCE ON ROAD

FIG.7

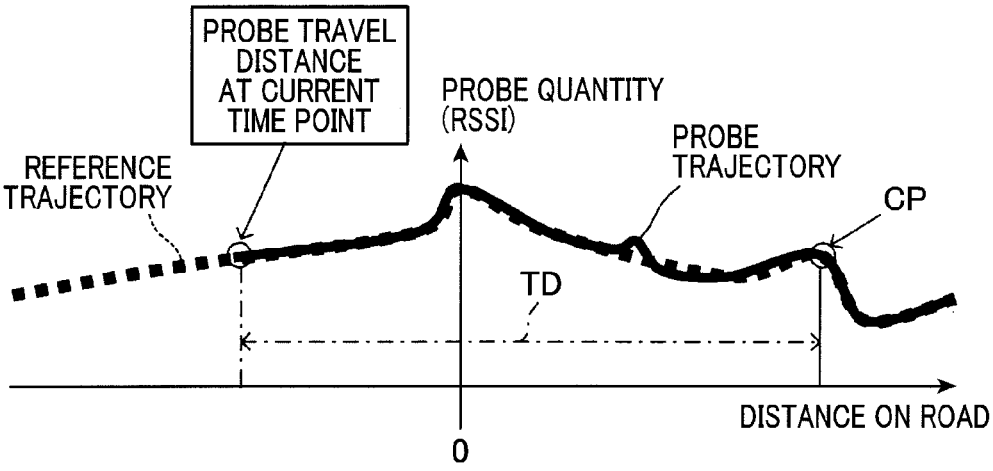

PROBE TRAVEL DISTANCE AT CURRENT TIME POINT
PROBE QUANTITY (RSSI)
REFERENCE TRAJECTORY
PROBE TRAJECTORY
CP
TD
DISTANCE ON ROAD
0

FIG.8

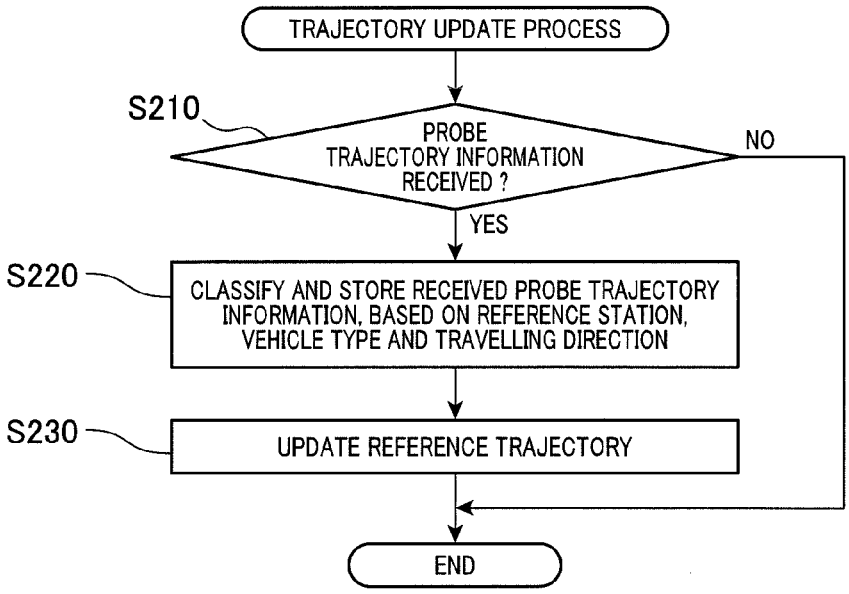

TRAJECTORY UPDATE PROCESS
S210
PROBE TRAJECTORY INFORMATION RECEIVED ?
NO
YES
S220
CLASSIFY AND STORE RECEIVED PROBE TRAJECTORY INFORMATION, BASED ON REFERENCE STATION, VEHICLE TYPE AND TRAVELLING DIRECTION
S230
UPDATE REFERENCE TRAJECTORY
END

FIG.9

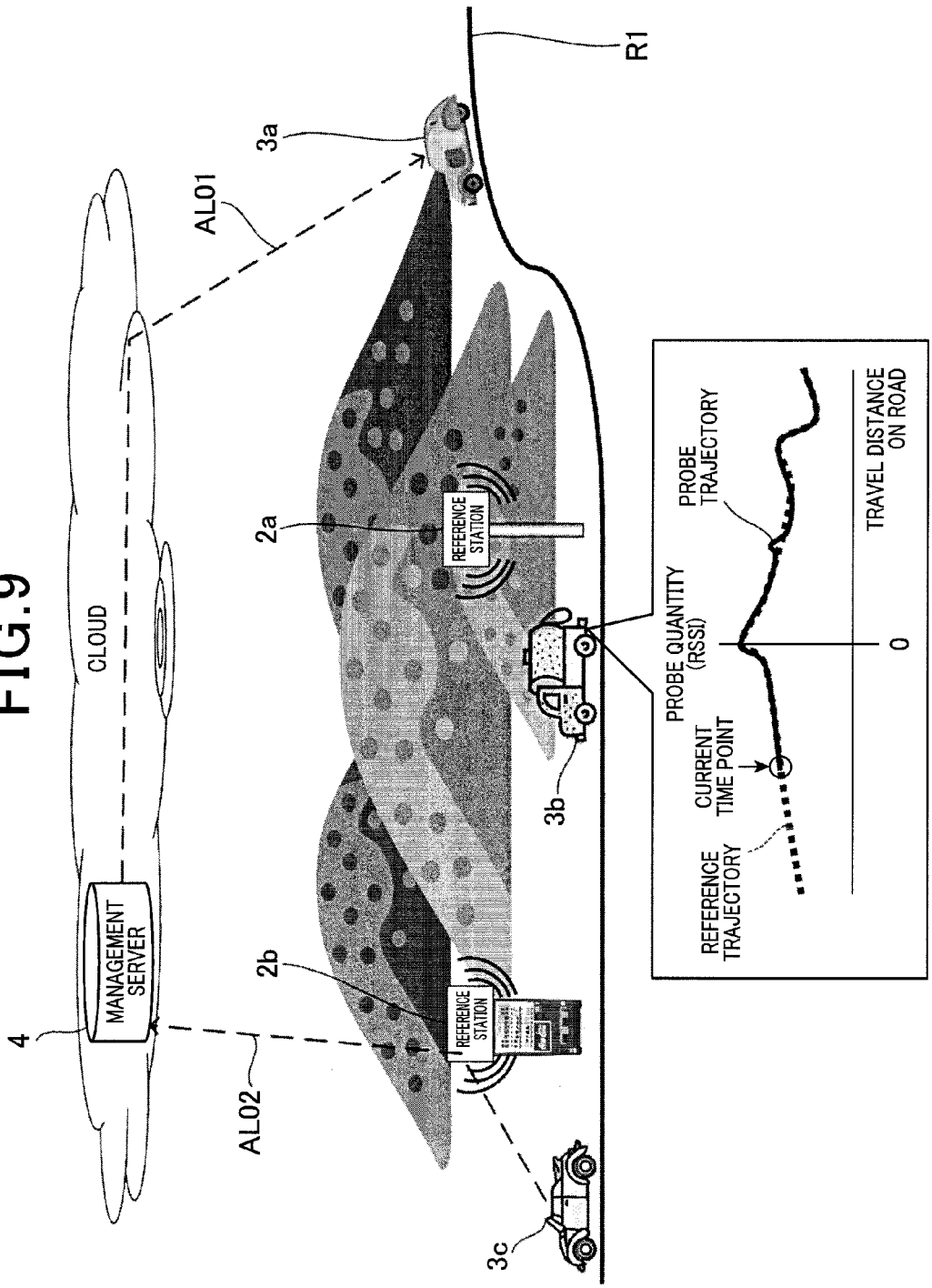

R1
3a
AL01
CLOUD
2a
REFERENCE STATION
MANAGEMENT SERVER
4
2b
REFERENCE STATION
AL02
3b
3c
PROBE QUANTITY (RSSI)
PROBE TRAJECTORY
CURRENT TIME POINT
REFERENCE TRAJECTORY
0
TRAVEL DISTANCE ON ROAD

FIG. 10

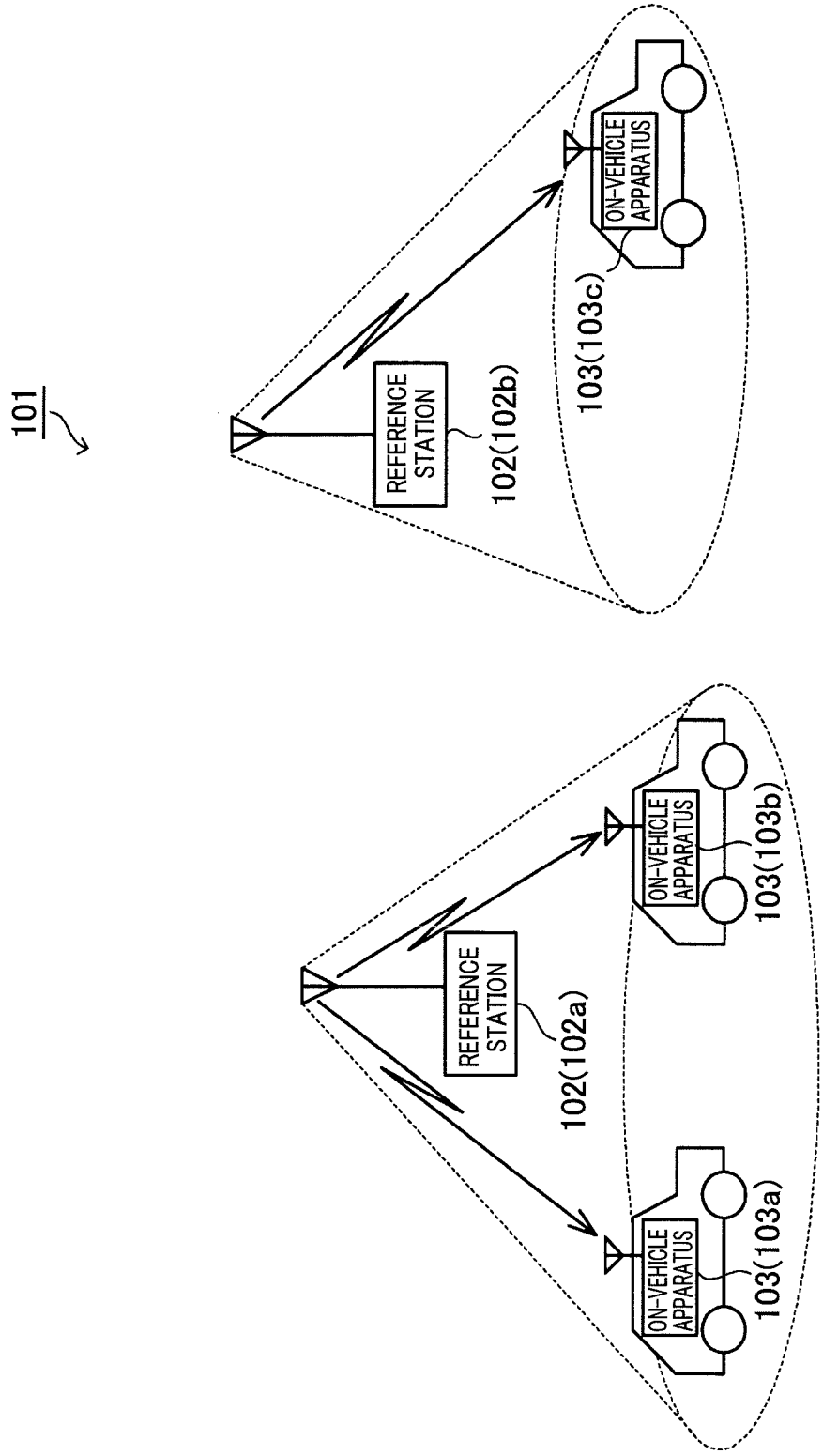

101
REFERENCE STATION
102(102b)
ON-VEHICLE APPARATUS
103(103c)
REFERENCE STATION
102(102a)
ON-VEHICLE APPARATUS
103(103b)
ON-VEHICLE APPARATUS
103(103a)

FIG.11

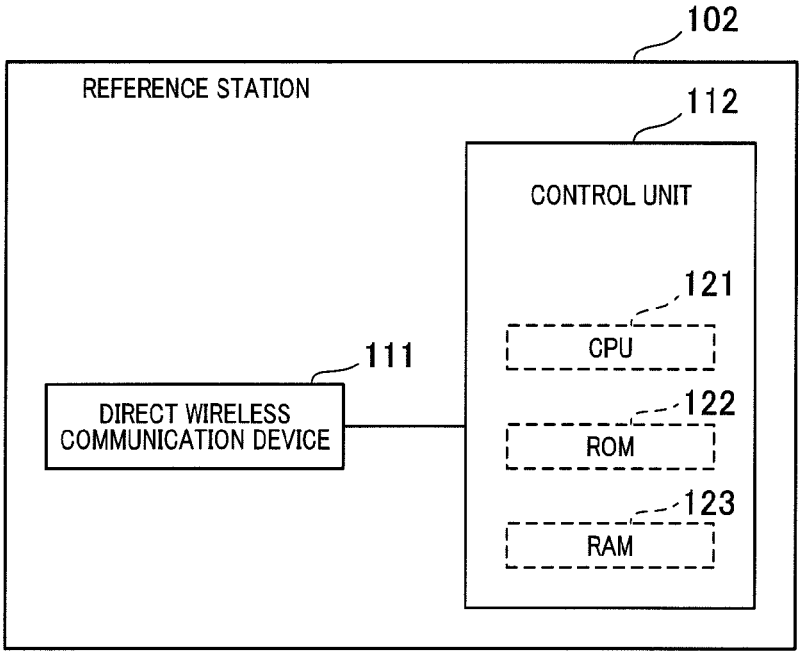

102
REFERENCE STATION
112
CONTROL UNIT
121
CPU
111
DIRECT WIRELESS COMMUNICATION DEVICE
122
ROM
123
RAM

FIG.12

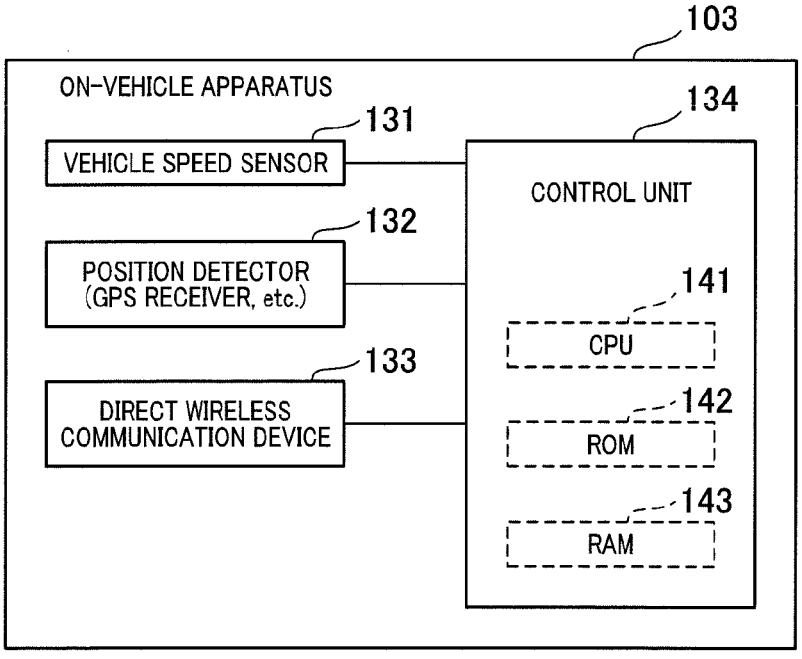

103
ON-VEHICLE APPARATUS
131
VEHICLE SPEED SENSOR
134
CONTROL UNIT
132
POSITION DETECTOR (GPS RECEIVER, etc.)
141
CPU
133
DIRECT WIRELESS COMMUNICATION DEVICE
142
ROM
143
RAM

FIG. 13

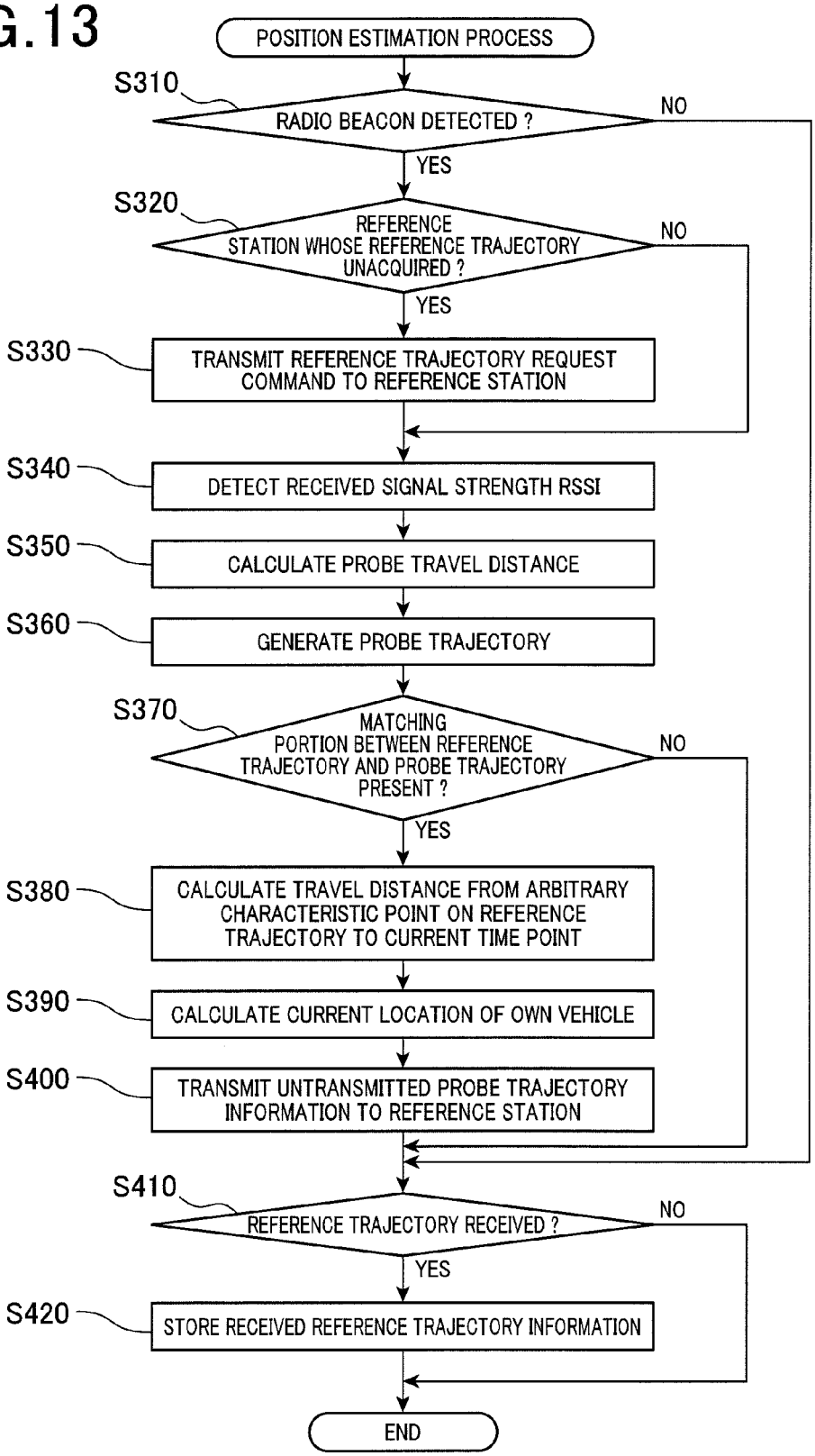

POSITION ESTIMATION PROCESS
S310
RADIO BEACON DETECTED ?
NO
YES
S320
REFERENCE STATION WHOSE REFERENCE TRAJECTORY UNACQUIRED ?
NO
YES
S330
TRANSMIT REFERENCE TRAJECTORY REQUEST COMMAND TO REFERENCE STATION
S340
DETECT RECEIVED SIGNAL STRENGTH RSSI
S350
CALCULATE PROBE TRAVEL DISTANCE
S360
GENERATE PROBE TRAJECTORY
S370
MATCHING PORTION BETWEEN REFERENCE TRAJECTORY AND PROBE TRAJECTORY PRESENT ?
NO
YES
S380
CALCULATE TRAVEL DISTANCE FROM ARBITRARY CHARACTERISTIC POINT ON REFERENCE TRAJECTORY TO CURRENT TIME POINT
S390
CALCULATE CURRENT LOCATION OF OWN VEHICLE
S400
TRANSMIT UNTRANSMITTED PROBE TRAJECTORY INFORMATION TO REFERENCE STATION
S410
REFERENCE TRAJECTORY RECEIVED ?
NO
YES
S420
STORE RECEIVED REFERENCE TRAJECTORY INFORMATION
END

FIG.14

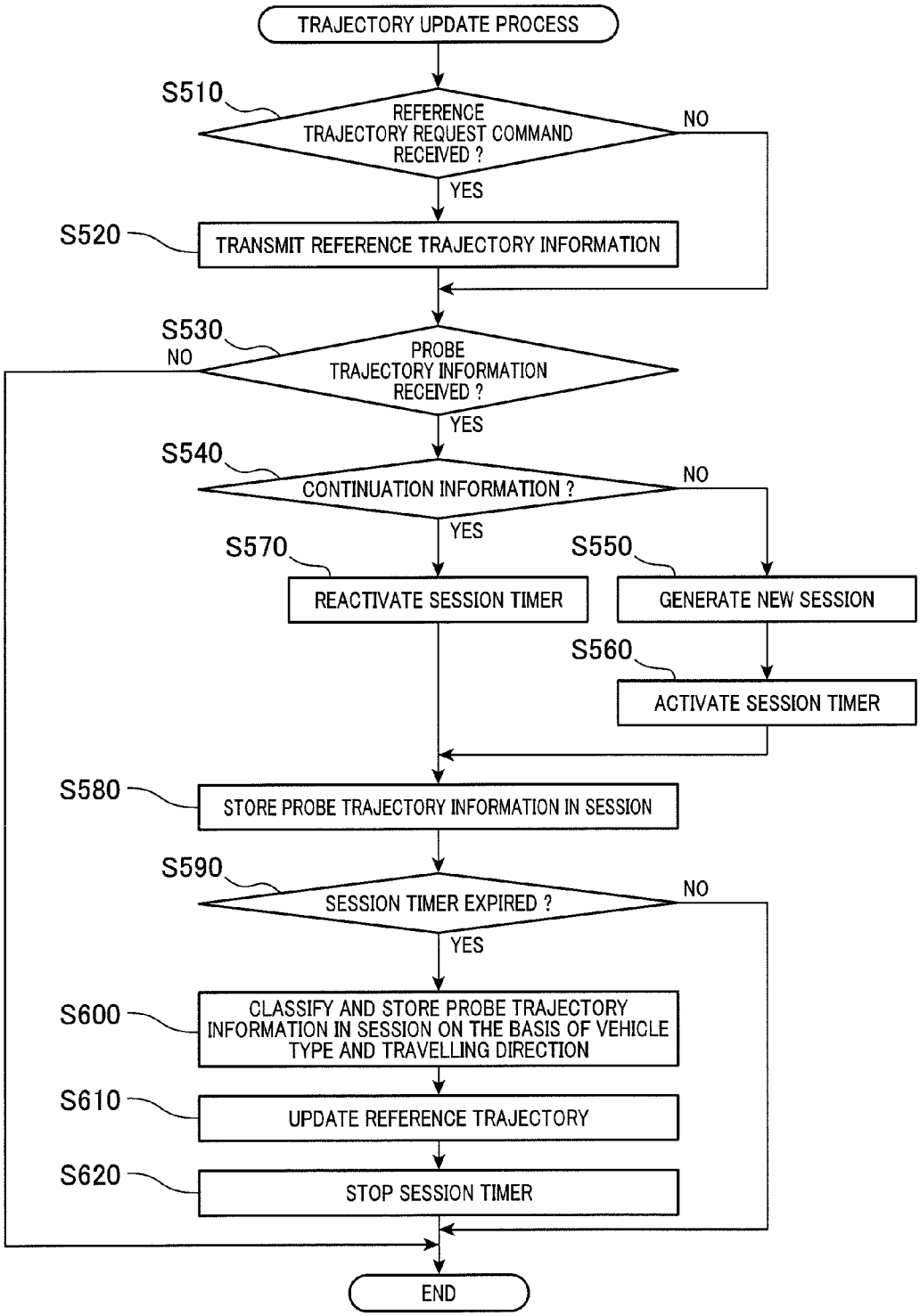

TRAJECTORY UPDATE PROCESS
S510
REFERENCE TRAJECTORY REQUEST COMMAND RECEIVED ?
NO
YES
S520
TRANSMIT REFERENCE TRAJECTORY INFORMATION
S530
NO
PROBE TRAJECTORY INFORMATION RECEIVED ?
YES
S540
CONTINUATION INFORMATION ?
NO
YES
S570
REACTIVATE SESSION TIMER
S550
GENERATE NEW SESSION
S560
ACTIVATE SESSION TIMER
S580
STORE PROBE TRAJECTORY INFORMATION IN SESSION
S590
SESSION TIMER EXPIRED ?
NO
YES
S600
CLASSIFY AND STORE PROBE TRAJECTORY INFORMATION IN SESSION ON THE BASIS OF VEHICLE TYPE AND TRAVELLING DIRECTION
S610
UPDATE REFERENCE TRAJECTORY
S620
STOP SESSION TIMER
END

FIG.15

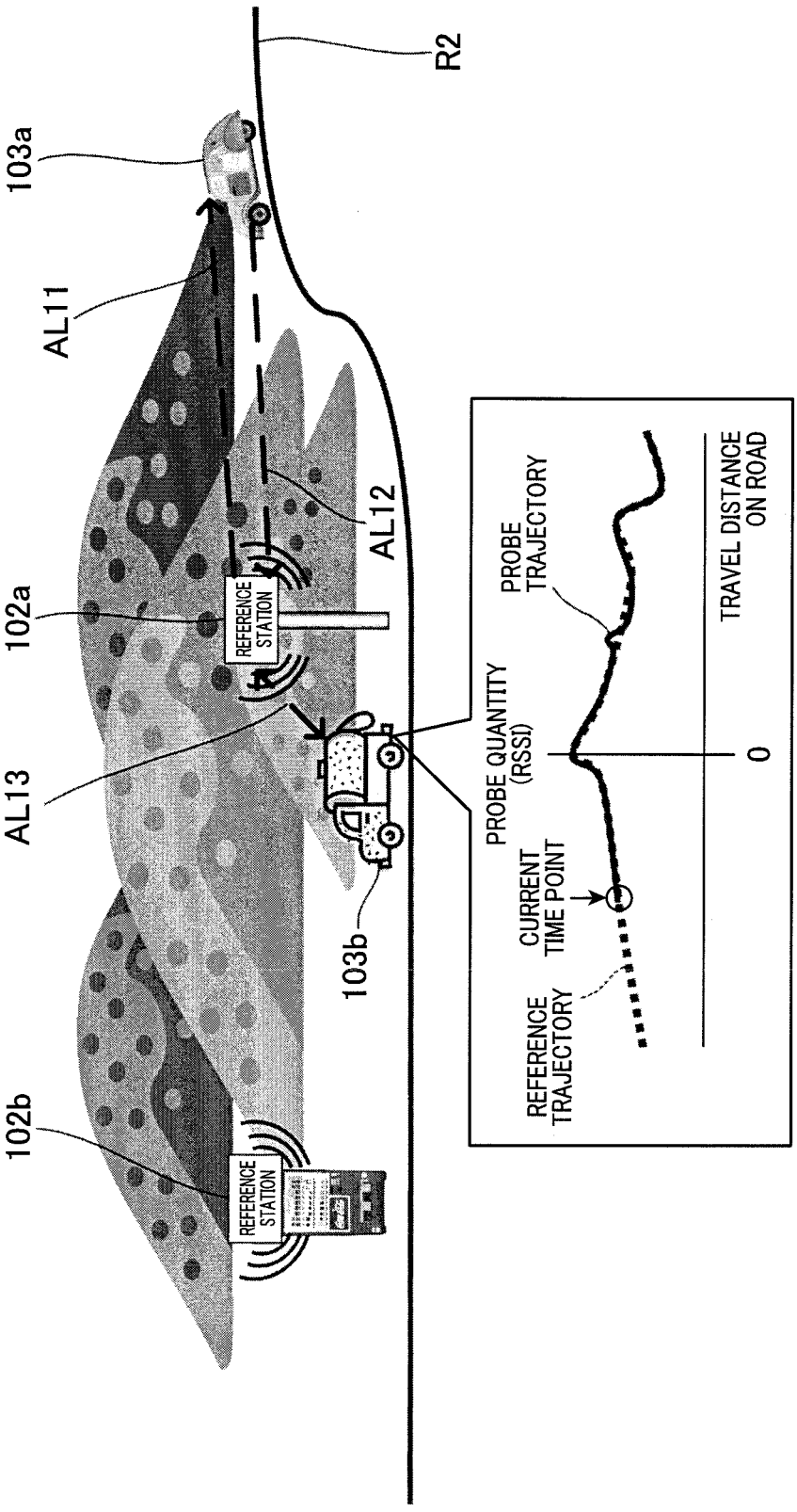

R2
103a
AL11
AL12
102a
REFERENCE STATION
AL13
103b
102b
REFERENCE STATION
PROBE QUANTITY (RSSI)
PROBE TRAJECTORY
CURRENT TIME POINT
REFERENCE TRAJECTORY
0
TRAVEL DISTANCE ON ROAD

FIG.16

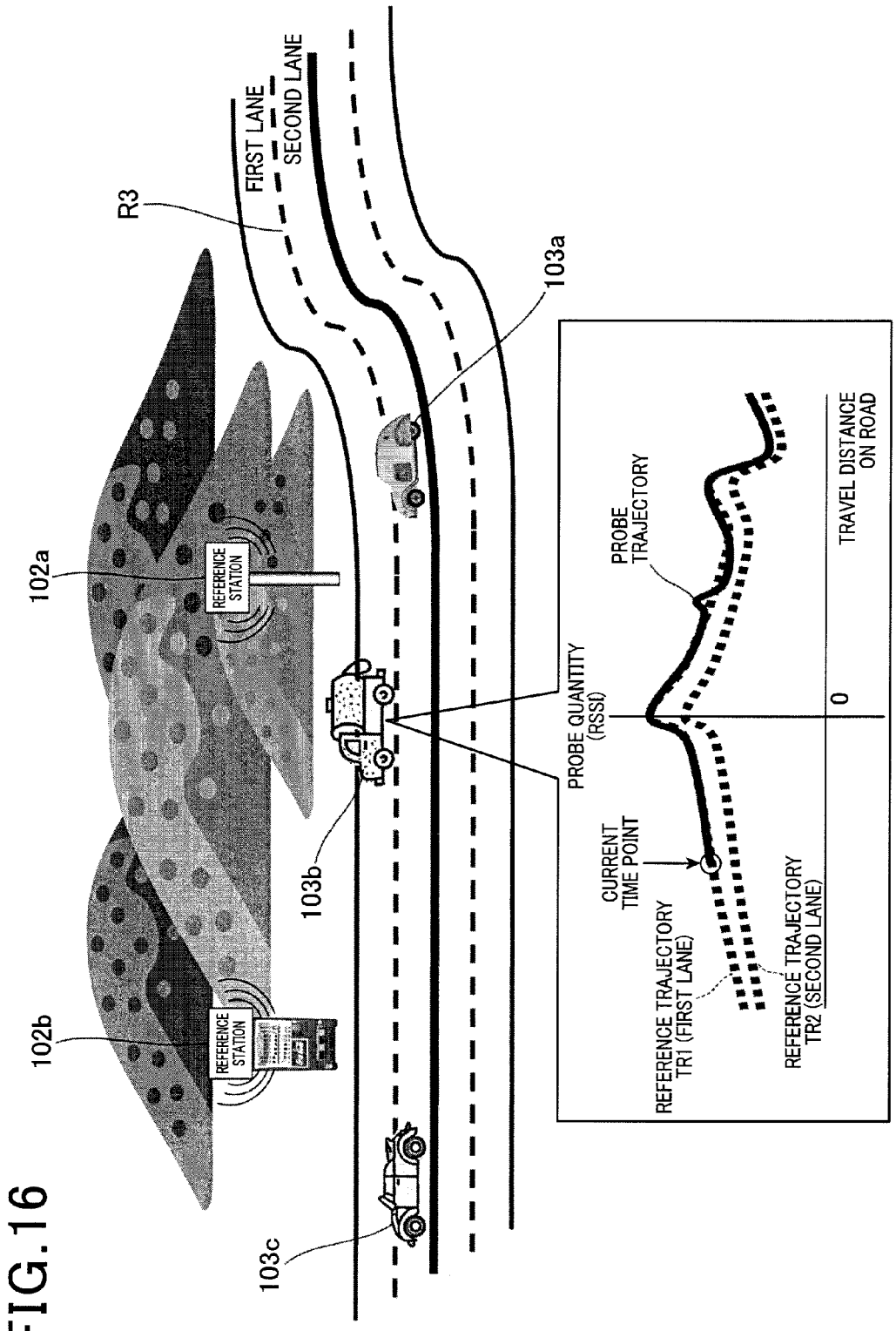

R3
FIRST LANE
SECOND LANE
103a
102a
REFERENCE STATION
103b
102b
REFERENCE STATION
103c
PROBE QUANTITY (RSSI)
PROBE TRAJECTORY
CURRENT TIME POINT
REFERENCE TRAJECTORY TR1 (FIRST LANE)
REFERENCE TRAJECTORY TR2 (SECOND LANE)
0
TRAVEL DISTANCE ON ROAD

FIG.17

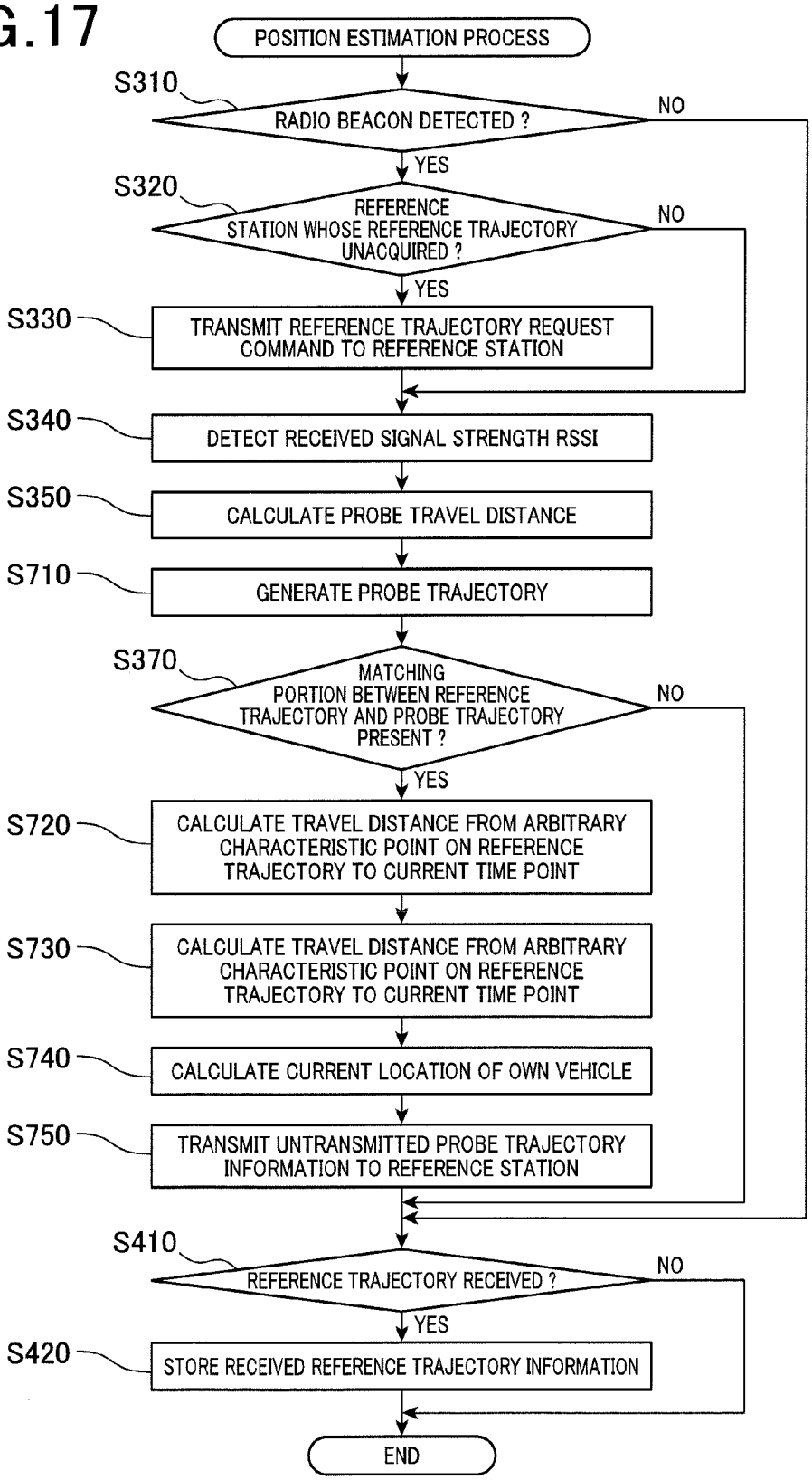

POSITION ESTIMATION PROCESS
S310
RADIO BEACON DETECTED ?
NO
YES
S320
REFERENCE STATION WHOSE REFERENCE TRAJECTORY UNACQUIRED ?
NO
YES
S330
TRANSMIT REFERENCE TRAJECTORY REQUEST COMMAND TO REFERENCE STATION
S340
DETECT RECEIVED SIGNAL STRENGTH RSSI
S350
CALCULATE PROBE TRAVEL DISTANCE
S710
GENERATE PROBE TRAJECTORY
S370
MATCHING PORTION BETWEEN REFERENCE TRAJECTORY AND PROBE TRAJECTORY PRESENT ?
NO
YES
S720
CALCULATE TRAVEL DISTANCE FROM ARBITRARY CHARACTERISTIC POINT ON REFERENCE TRAJECTORY TO CURRENT TIME POINT
S730
CALCULATE TRAVEL DISTANCE FROM ARBITRARY CHARACTERISTIC POINT ON REFERENCE TRAJECTORY TO CURRENT TIME POINT
S740
CALCULATE CURRENT LOCATION OF OWN VEHICLE
S750
TRANSMIT UNTRANSMITTED PROBE TRAJECTORY INFORMATION TO REFERENCE STATION
S410
REFERENCE TRAJECTORY RECEIVED ?
NO
YES
S420
STORE RECEIVED REFERENCE TRAJECTORY INFORMATION
END

FIG.18

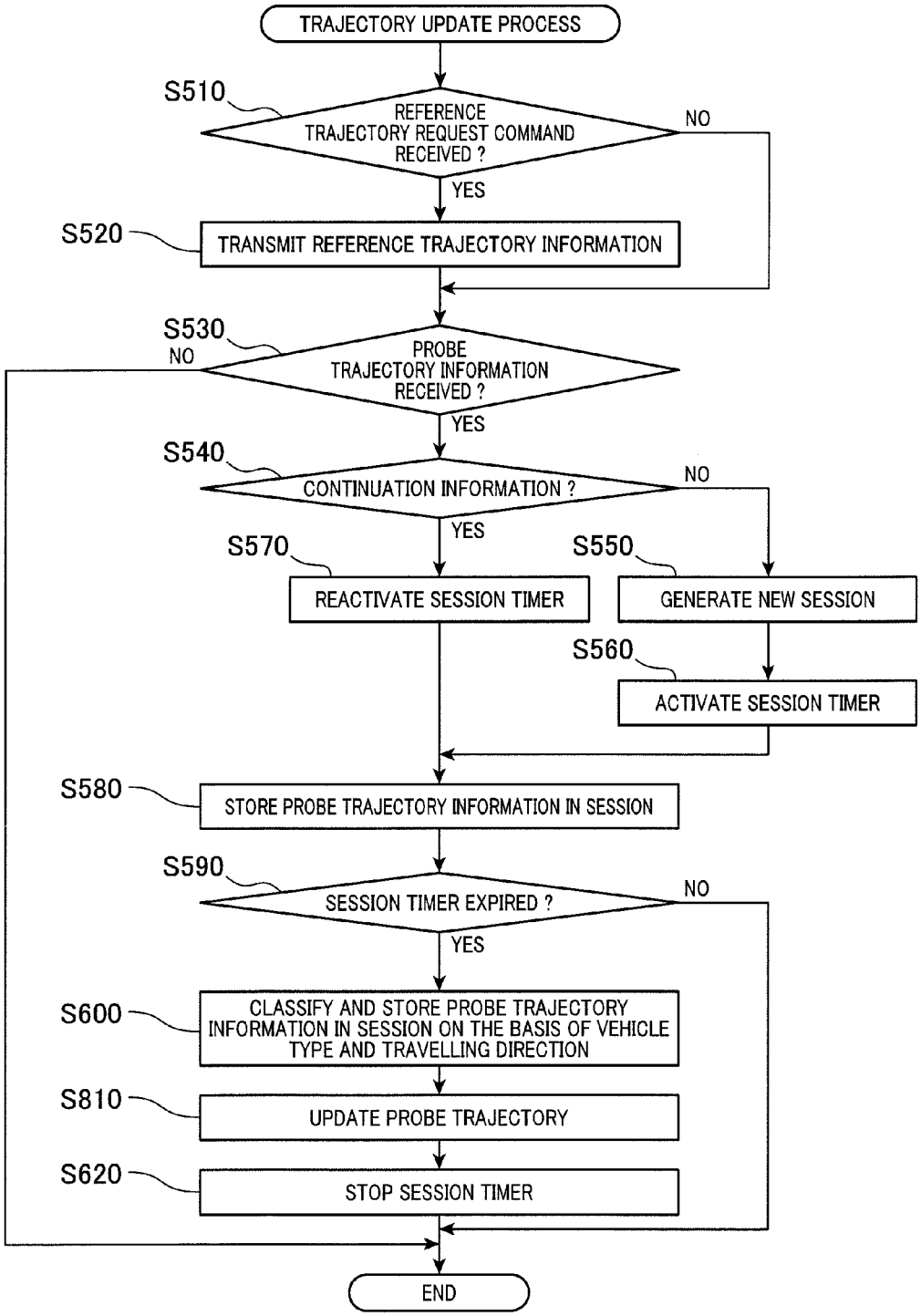

TRAJECTORY UPDATE PROCESS
S510
REFERENCE TRAJECTORY REQUEST COMMAND RECEIVED ?
NO
YES
S520
TRANSMIT REFERENCE TRAJECTORY INFORMATION
S530
NO
PROBE TRAJECTORY INFORMATION RECEIVED ?
YES
S540
CONTINUATION INFORMATION ?
NO
YES
S570
REACTIVATE SESSION TIMER
S550
GENERATE NEW SESSION
S560
ACTIVATE SESSION TIMER
S580
STORE PROBE TRAJECTORY INFORMATION IN SESSION
S590
SESSION TIMER EXPIRED ?
NO
YES
S600
CLASSIFY AND STORE PROBE TRAJECTORY INFORMATION IN SESSION ON THE BASIS OF VEHICLE TYPE AND TRAVELLING DIRECTION
S810
UPDATE PROBE TRAJECTORY
S620
STOP SESSION TIMER
END

FIG.19

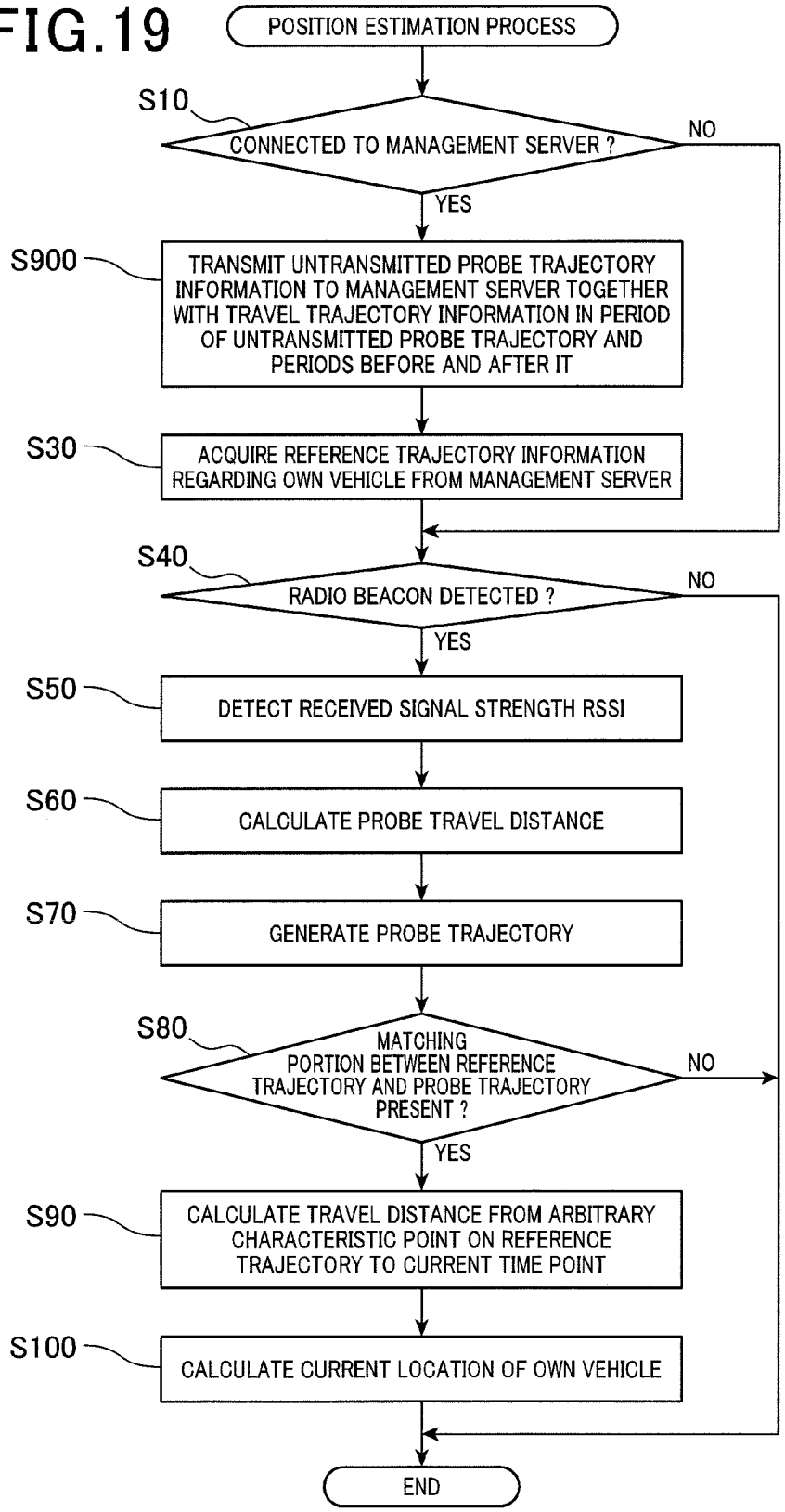

POSITION ESTIMATION PROCESS
S10
CONNECTED TO MANAGEMENT SERVER ?
NO
YES
S900
TRANSMIT UNTRANSMITTED PROBE TRAJECTORY INFORMATION TO MANAGEMENT SERVER TOGETHER WITH TRAVEL TRAJECTORY INFORMATION IN PERIOD OF UNTRANSMITTED PROBE TRAJECTORY AND PERIODS BEFORE AND AFTER IT
S30
ACQUIRE REFERENCE TRAJECTORY INFORMATION REGARDING OWN VEHICLE FROM MANAGEMENT SERVER
S40
RADIO BEACON DETECTED ?
NO
YES
S50
DETECT RECEIVED SIGNAL STRENGTH RSSI
S60
CALCULATE PROBE TRAVEL DISTANCE
S70
GENERATE PROBE TRAJECTORY
S80
MATCHING PORTION BETWEEN REFERENCE TRAJECTORY AND PROBE TRAJECTORY PRESENT ?
NO
YES
S90
CALCULATE TRAVEL DISTANCE FROM ARBITRARY CHARACTERISTIC POINT ON REFERENCE TRAJECTORY TO CURRENT TIME POINT
S100
CALCULATE CURRENT LOCATION OF OWN VEHICLE
END

FIG.20

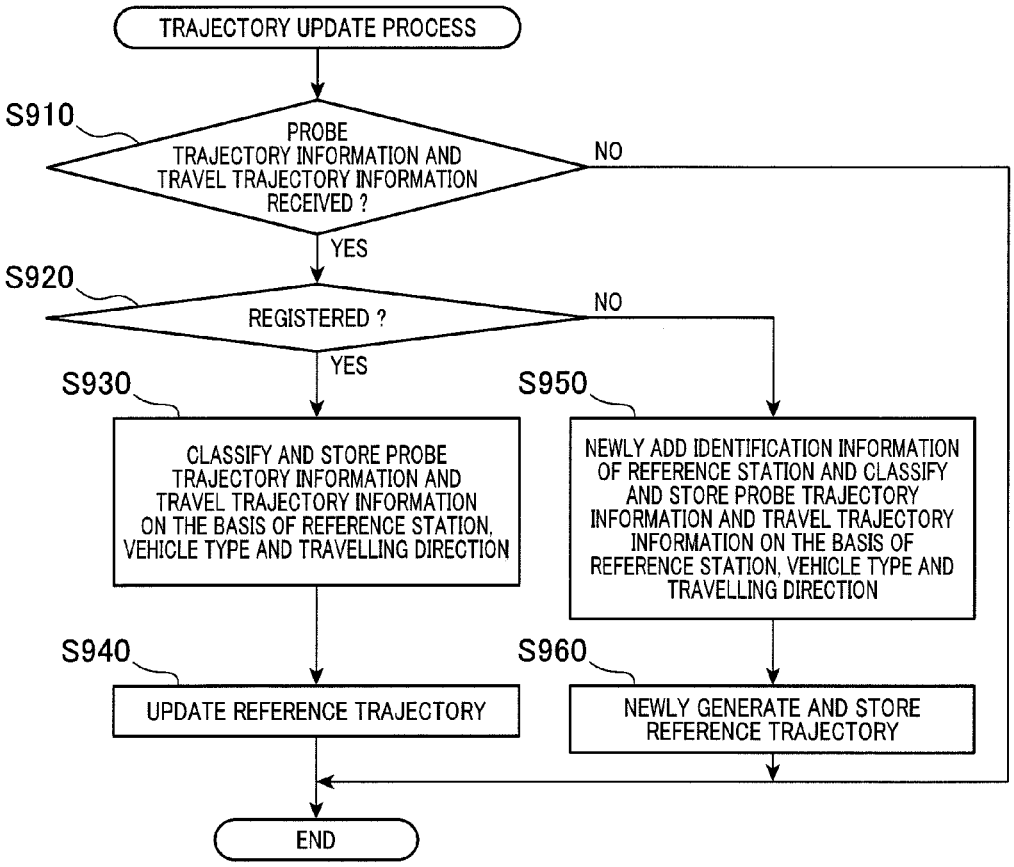

TRAJECTORY UPDATE PROCESS
S910
PROBE TRAJECTORY INFORMATION AND TRAVEL TRAJECTORY INFORMATION RECEIVED ?
NO
YES
S920
REGISTERED ?
NO
YES
S930
CLASSIFY AND STORE PROBE TRAJECTORY INFORMATION AND TRAVEL TRAJECTORY INFORMATION ON THE BASIS OF REFERENCE STATION, VEHICLE TYPE AND TRAVELLING DIRECTION
S940
UPDATE REFERENCE TRAJECTORY
S950
NEWLY ADD IDENTIFICATION INFORMATION OF REFERENCE STATION AND CLASSIFY AND STORE PROBE TRAJECTORY INFORMATION AND TRAVEL TRAJECTORY INFORMATION ON THE BASIS OF REFERENCE STATION, VEHICLE TYPE AND TRAVELLING DIRECTION
S960
NEWLY GENERATE AND STORE REFERENCE TRAJECTORY
END

FIG.21

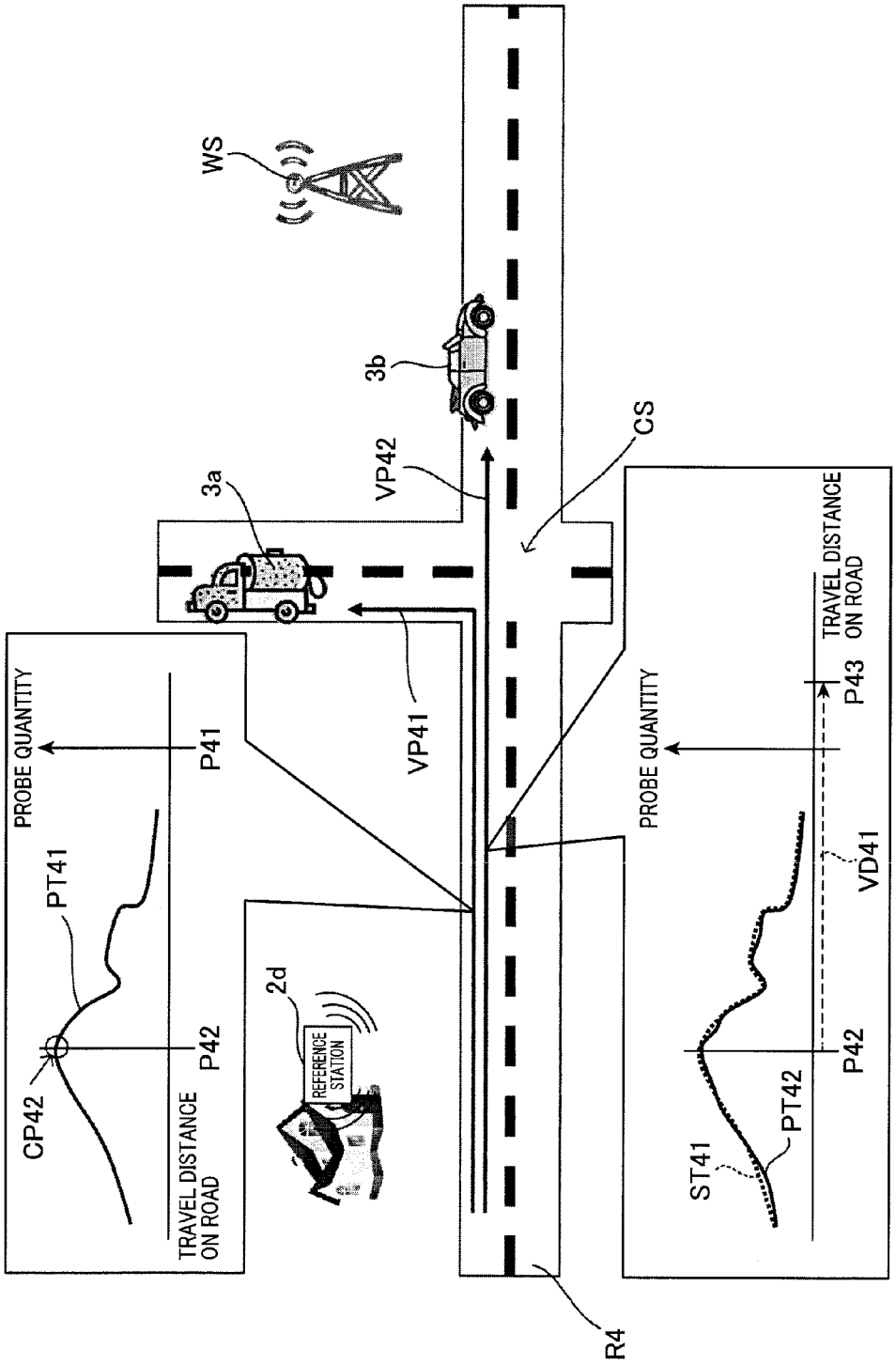

WS
3b
3a
VP42
CS
VP41
2d
REFERENCE STATION
R4
PROBE QUANTITY
P41
PT41
CP42
P42
TRAVEL DISTANCE ON ROAD
PROBE QUANTITY
TRAVEL DISTANCE ON ROAD
P43
VD41
P42
PT42
ST41

FIG.22

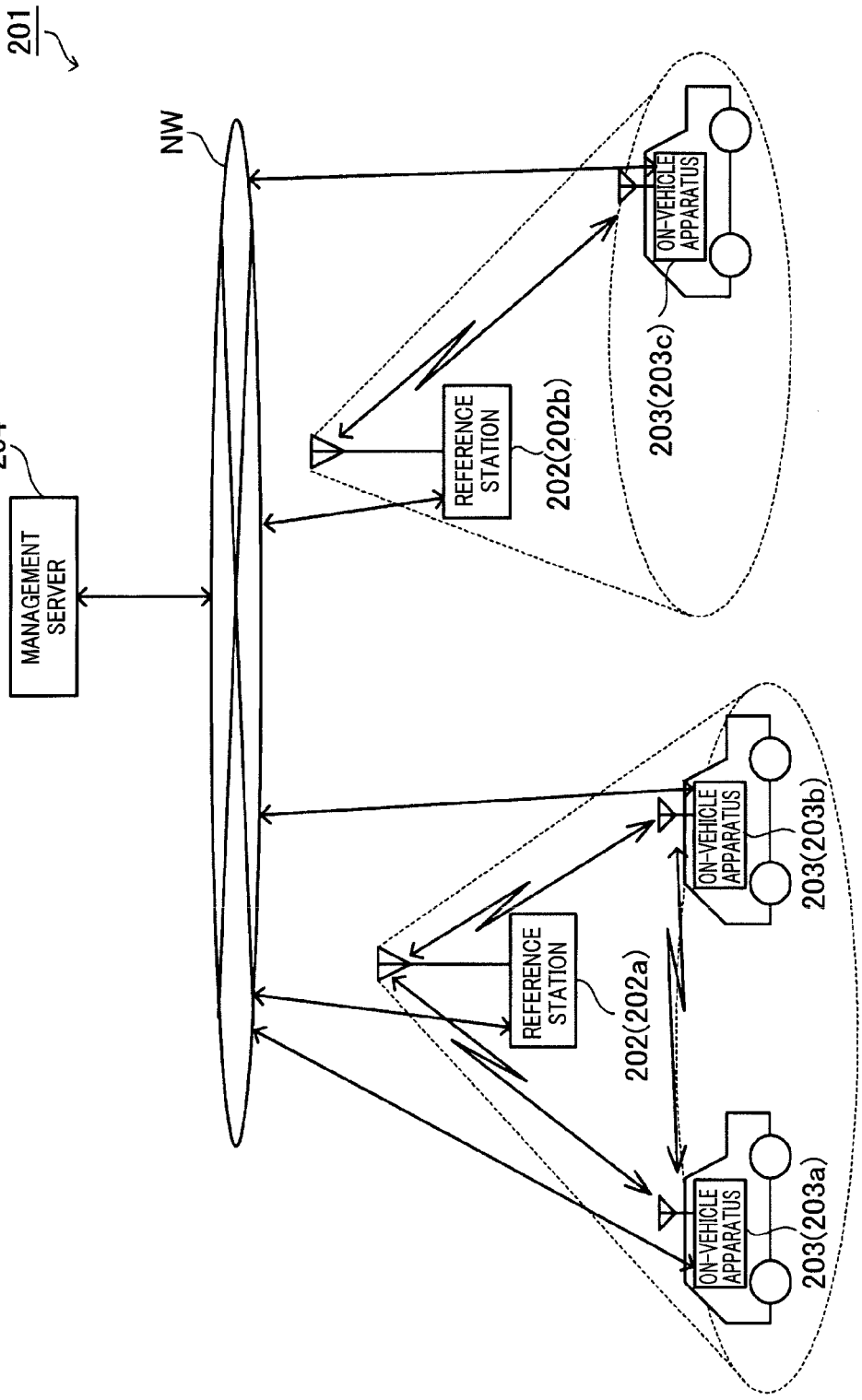

201
NW
204
MANAGEMENT SERVER
REFERENCE STATION
202(202b)
ON-VEHICLE APPARATUS
203(203c)
REFERENCE STATION
202(202a)
ON-VEHICLE APPARATUS
203(203b)
ON-VEHICLE APPARATUS
203(203a)

FIG.23

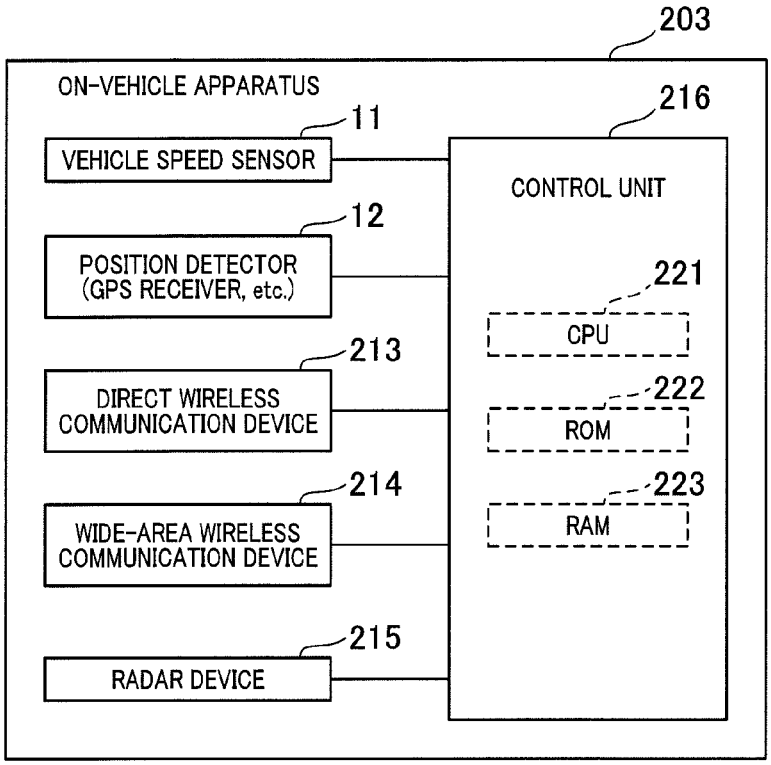

203
ON-VEHICLE APPARATUS
11
VEHICLE SPEED SENSOR
12
POSITION DETECTOR
(GPS RECEIVER, etc.)
213
DIRECT WIRELESS
COMMUNICATION DEVICE
214
WIDE-AREA WIRELESS
COMMUNICATION DEVICE
215
RADAR DEVICE
216
CONTROL UNIT
221
CPU
222
ROM
223
RAM

FIG.24

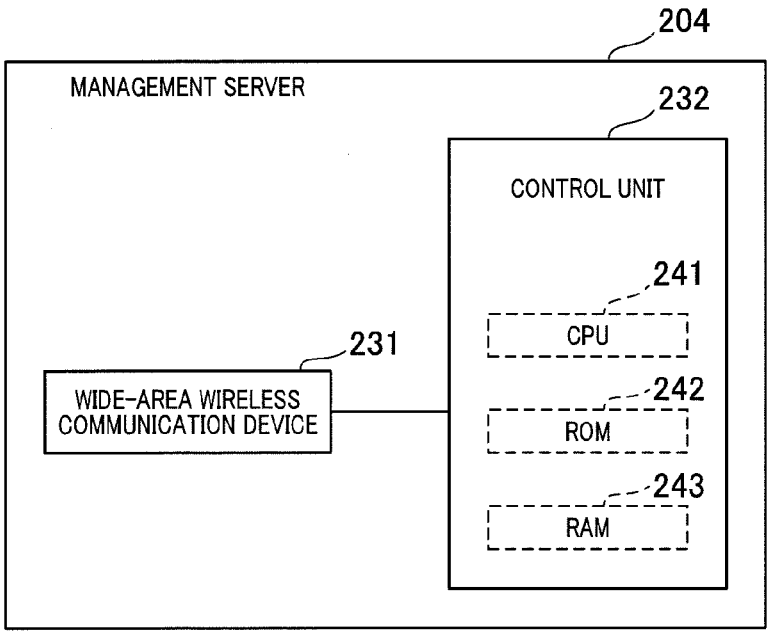

204
MANAGEMENT SERVER
231
WIDE-AREA WIRELESS
COMMUNICATION DEVICE
232
CONTROL UNIT
241
CPU
242
ROM
243
RAM

FIG.25

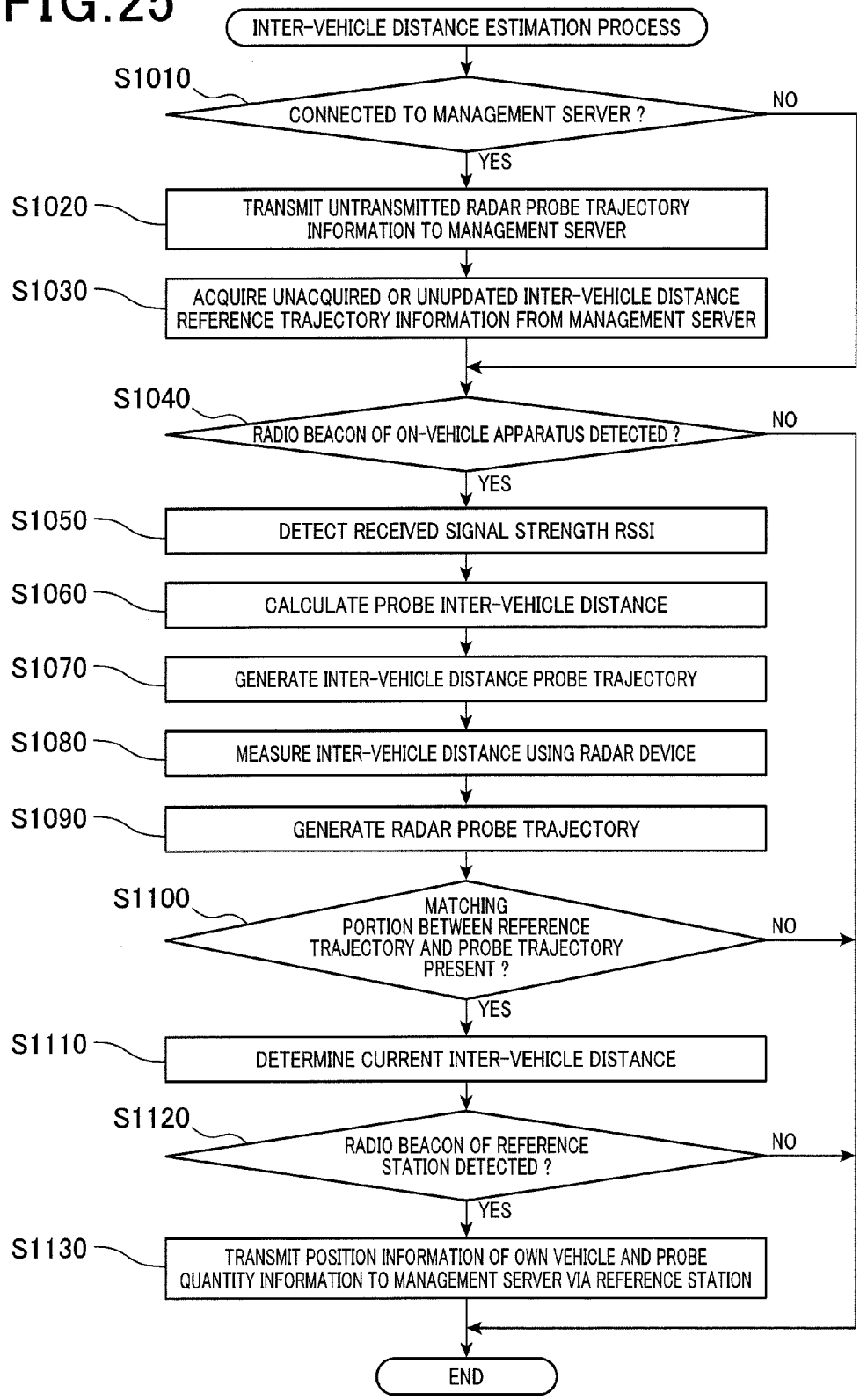

INTER-VEHICLE DISTANCE ESTIMATION PROCESS
S1010
CONNECTED TO MANAGEMENT SERVER ?
NO
YES
S1020
TRANSMIT UNTRANSMITTED RADAR PROBE TRAJECTORY INFORMATION TO MANAGEMENT SERVER
S1030
ACQUIRE UNACQUIRED OR UNUPDATED INTER-VEHICLE DISTANCE REFERENCE TRAJECTORY INFORMATION FROM MANAGEMENT SERVER
S1040
RADIO BEACON OF ON-VEHICLE APPARATUS DETECTED ?
NO
YES
S1050
DETECT RECEIVED SIGNAL STRENGTH RSSI
S1060
CALCULATE PROBE INTER-VEHICLE DISTANCE
S1070
GENERATE INTER-VEHICLE DISTANCE PROBE TRAJECTORY
S1080
MEASURE INTER-VEHICLE DISTANCE USING RADAR DEVICE
S1090
GENERATE RADAR PROBE TRAJECTORY
S1100
MATCHING PORTION BETWEEN REFERENCE TRAJECTORY AND PROBE TRAJECTORY PRESENT ?
NO
YES
S1110
DETERMINE CURRENT INTER-VEHICLE DISTANCE
S1120
RADIO BEACON OF REFERENCE STATION DETECTED ?
NO
YES
S1130
TRANSMIT POSITION INFORMATION OF OWN VEHICLE AND PROBE QUANTITY INFORMATION TO MANAGEMENT SERVER VIA REFERENCE STATION
END

FIG.26

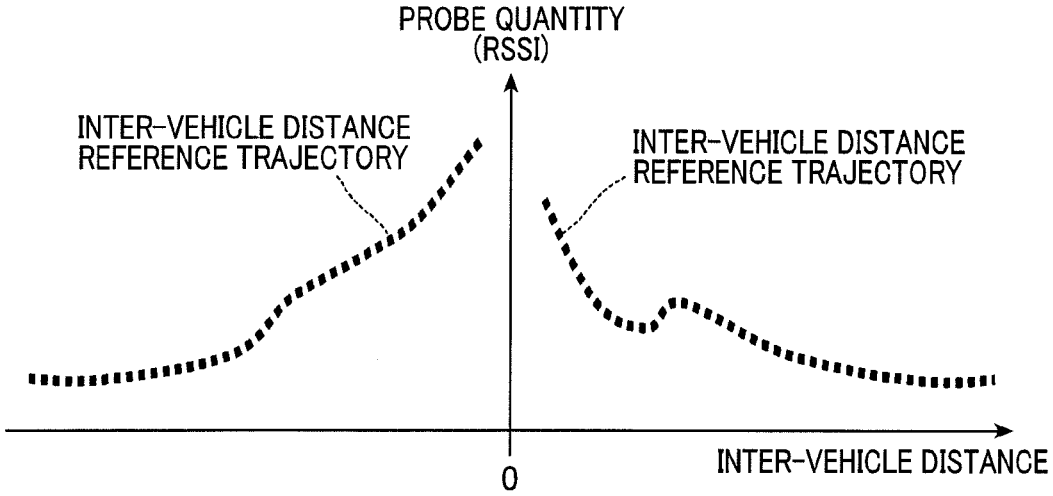

PROBE QUANTITY
(RSSI)
INTER-VEHICLE DISTANCE
REFERENCE TRAJECTORY
INTER-VEHICLE DISTANCE
REFERENCE TRAJECTORY
0
INTER-VEHICLE DISTANCE

FIG.27

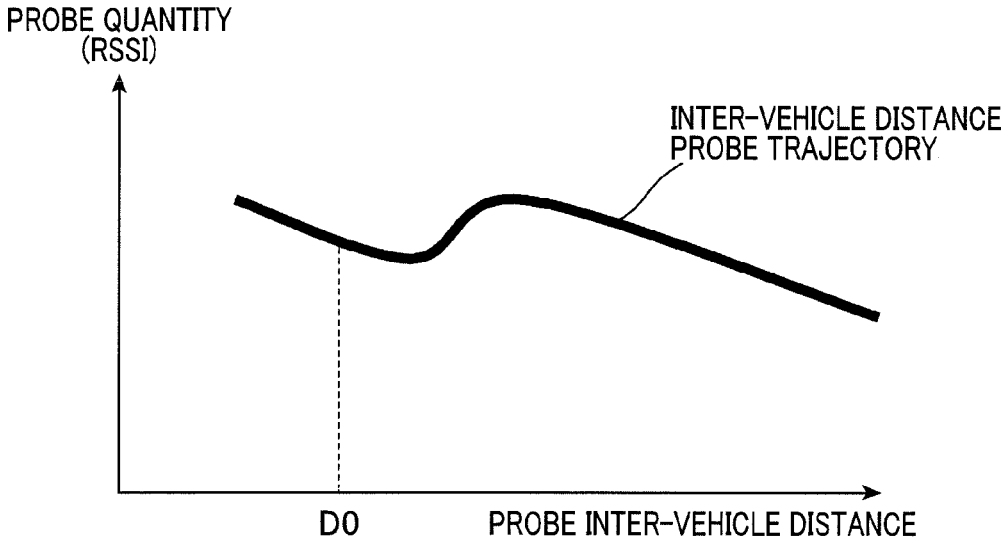

PROBE QUANTITY
(RSSI)
INTER-VEHICLE DISTANCE
PROBE TRAJECTORY
D0
PROBE INTER-VEHICLE DISTANCE

FIG.28

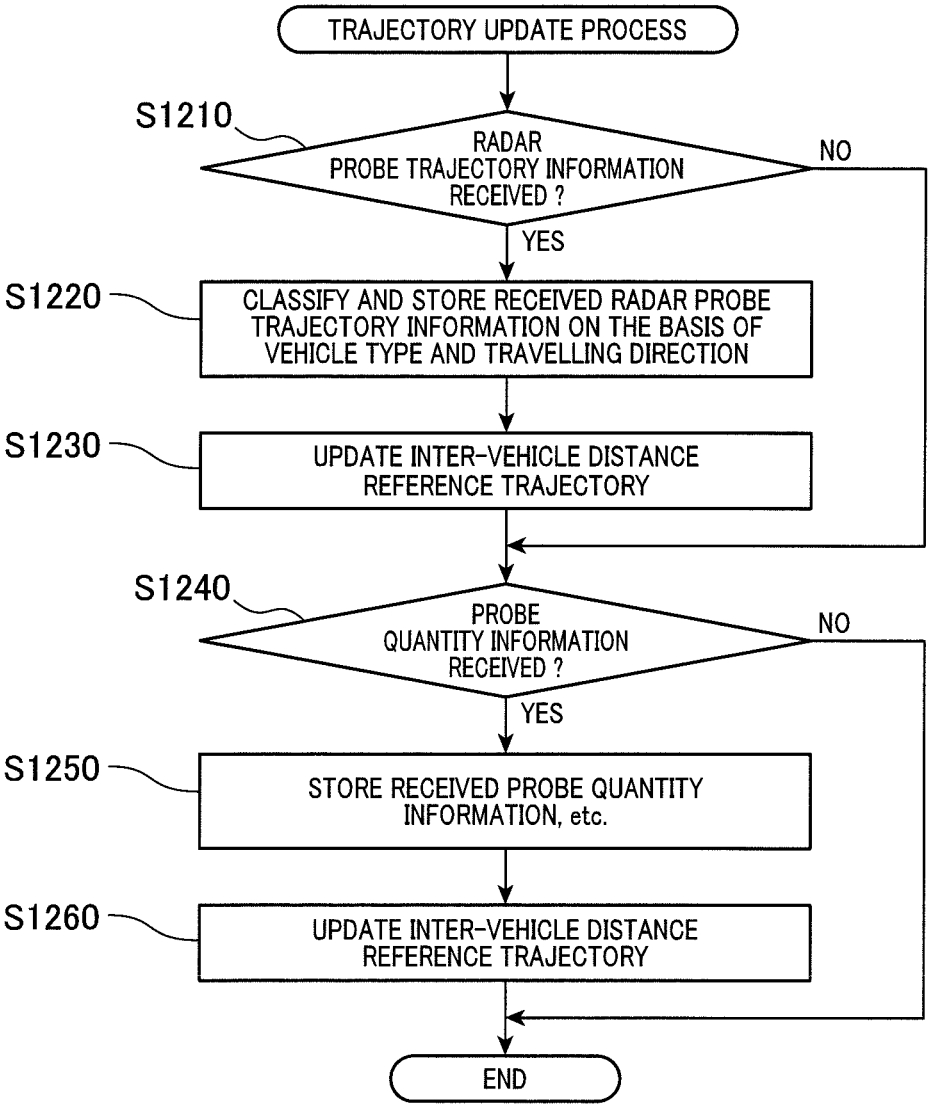

TRAJECTORY UPDATE PROCESS
S1210
RADAR PROBE TRAJECTORY INFORMATION RECEIVED ?
NO
YES
S1220
CLASSIFY AND STORE RECEIVED RADAR PROBE TRAJECTORY INFORMATION ON THE BASIS OF VEHICLE TYPE AND TRAVELLING DIRECTION
S1230
UPDATE INTER-VEHICLE DISTANCE REFERENCE TRAJECTORY
S1240
PROBE QUANTITY INFORMATION RECEIVED ?
NO
YES
S1250
STORE RECEIVED PROBE QUANTITY INFORMATION, etc.
S1260
UPDATE INTER-VEHICLE DISTANCE REFERENCE TRAJECTORY
END

FIG.29

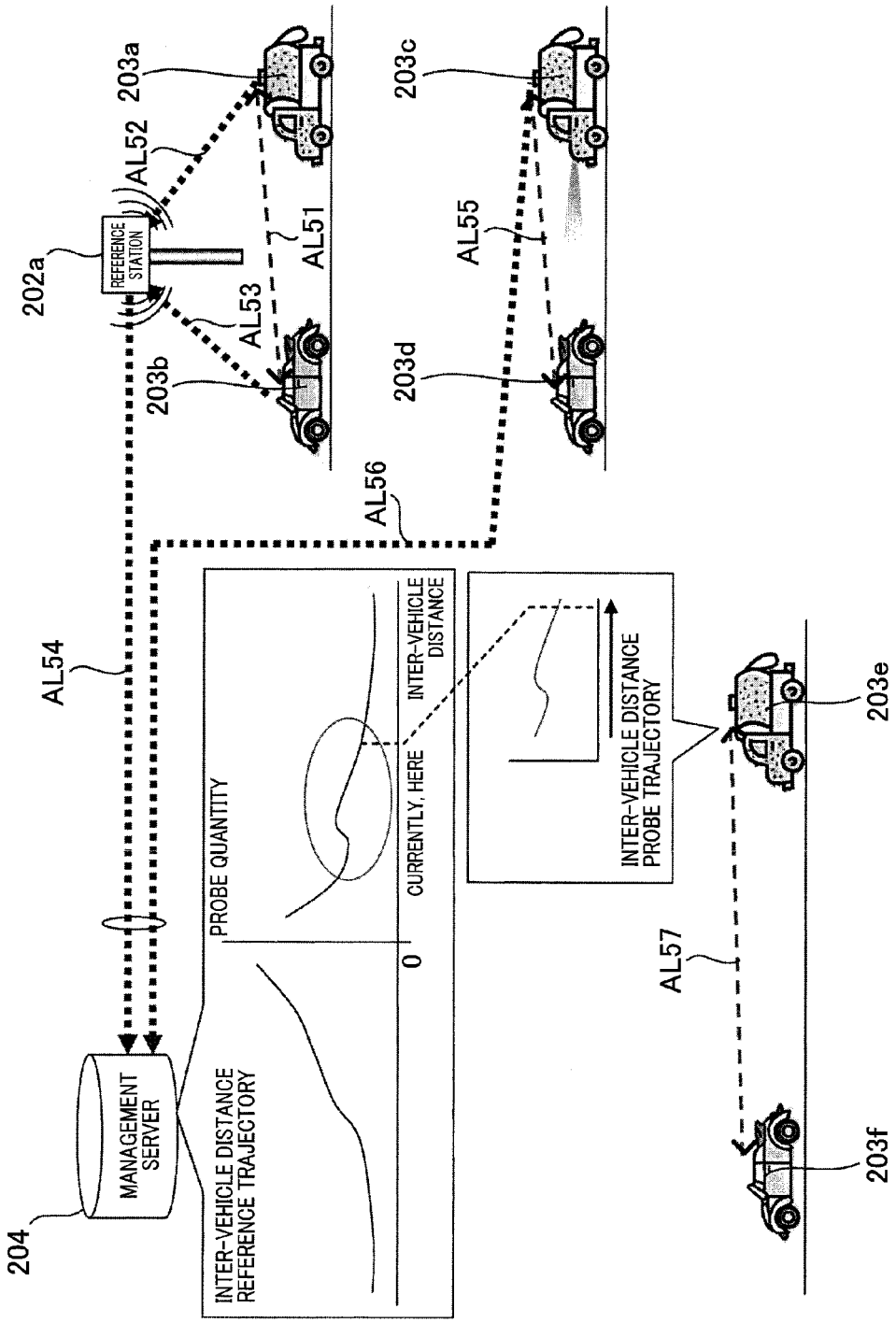

202a
REFERENCE STATION
203a
203b
203c
203d
203e
203f
AL51
AL52
AL53
AL54
AL55
AL56
AL57
204
MANAGEMENT SERVER
INTER-VEHICLE DISTANCE REFERENCE TRAJECTORY
PROBE QUANTITY
0
CURRENTLY, HERE
INTER-VEHICLE DISTANCE
INTER-VEHICLE DISTANCE PROBE TRAJECTORY

FIG.30

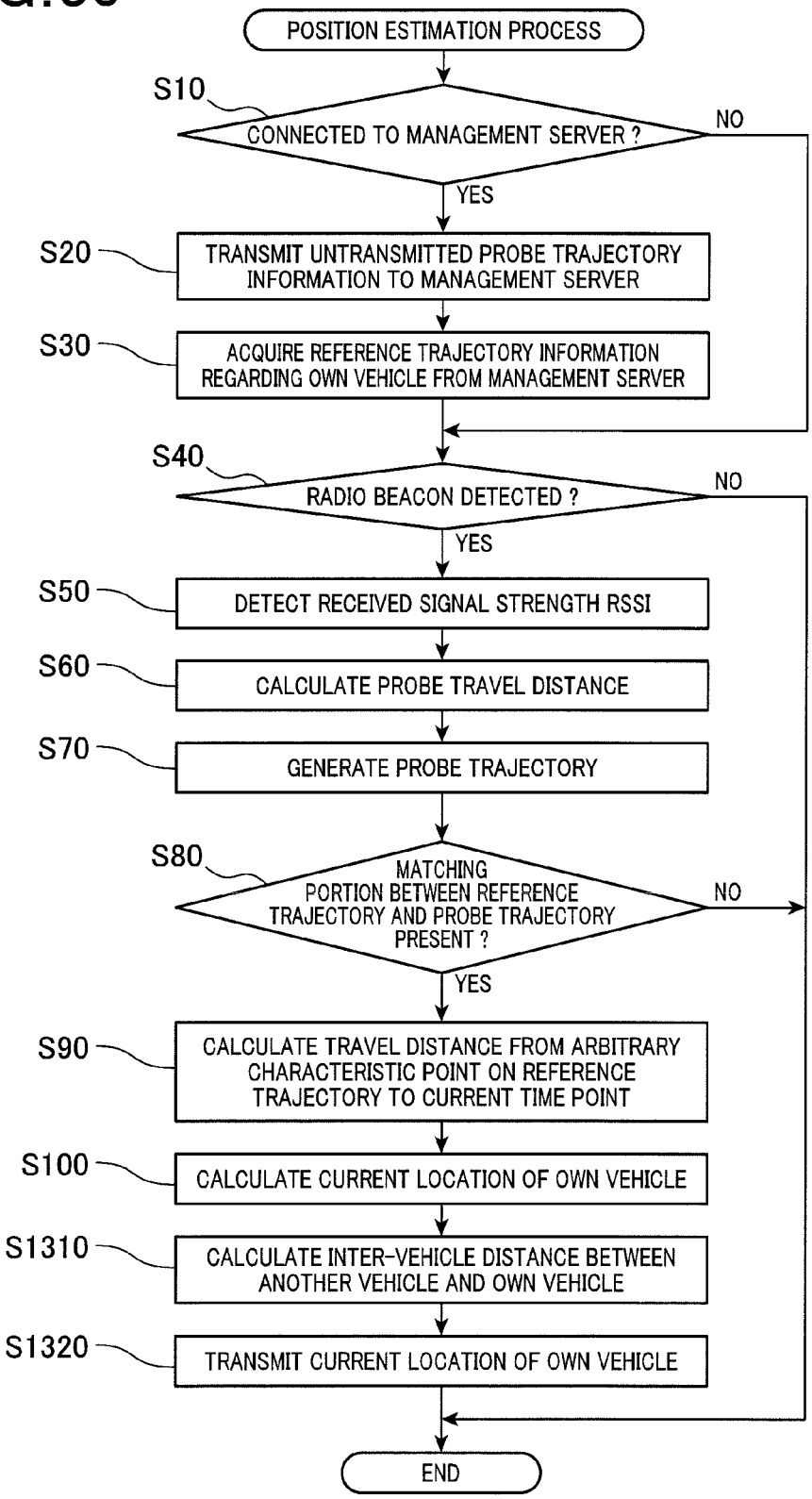

POSITION ESTIMATION PROCESS
S10
CONNECTED TO MANAGEMENT SERVER ?
NO
YES
S20
TRANSMIT UNTRANSMITTED PROBE TRAJECTORY INFORMATION TO MANAGEMENT SERVER
S30
ACQUIRE REFERENCE TRAJECTORY INFORMATION REGARDING OWN VEHICLE FROM MANAGEMENT SERVER
S40
RADIO BEACON DETECTED ?
NO
YES
S50
DETECT RECEIVED SIGNAL STRENGTH RSSI
S60
CALCULATE PROBE TRAVEL DISTANCE
S70
GENERATE PROBE TRAJECTORY
S80
MATCHING PORTION BETWEEN REFERENCE TRAJECTORY AND PROBE TRAJECTORY PRESENT ?
NO
YES
S90
CALCULATE TRAVEL DISTANCE FROM ARBITRARY CHARACTERISTIC POINT ON REFERENCE TRAJECTORY TO CURRENT TIME POINT
S100
CALCULATE CURRENT LOCATION OF OWN VEHICLE
S1310
CALCULATE INTER-VEHICLE DISTANCE BETWEEN ANOTHER VEHICLE AND OWN VEHICLE
S1320
TRANSMIT CURRENT LOCATION OF OWN VEHICLE
END

FIG.31

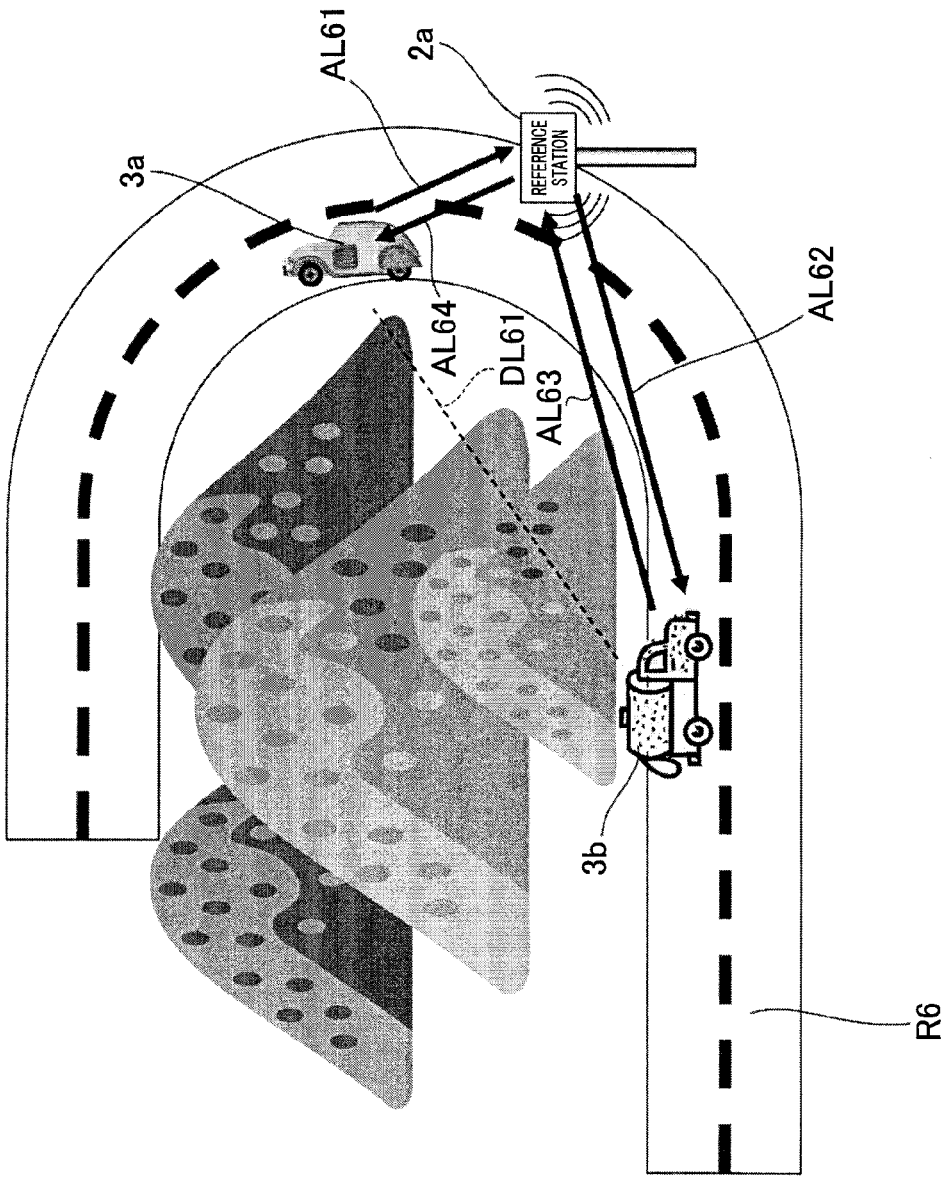


FIG.32

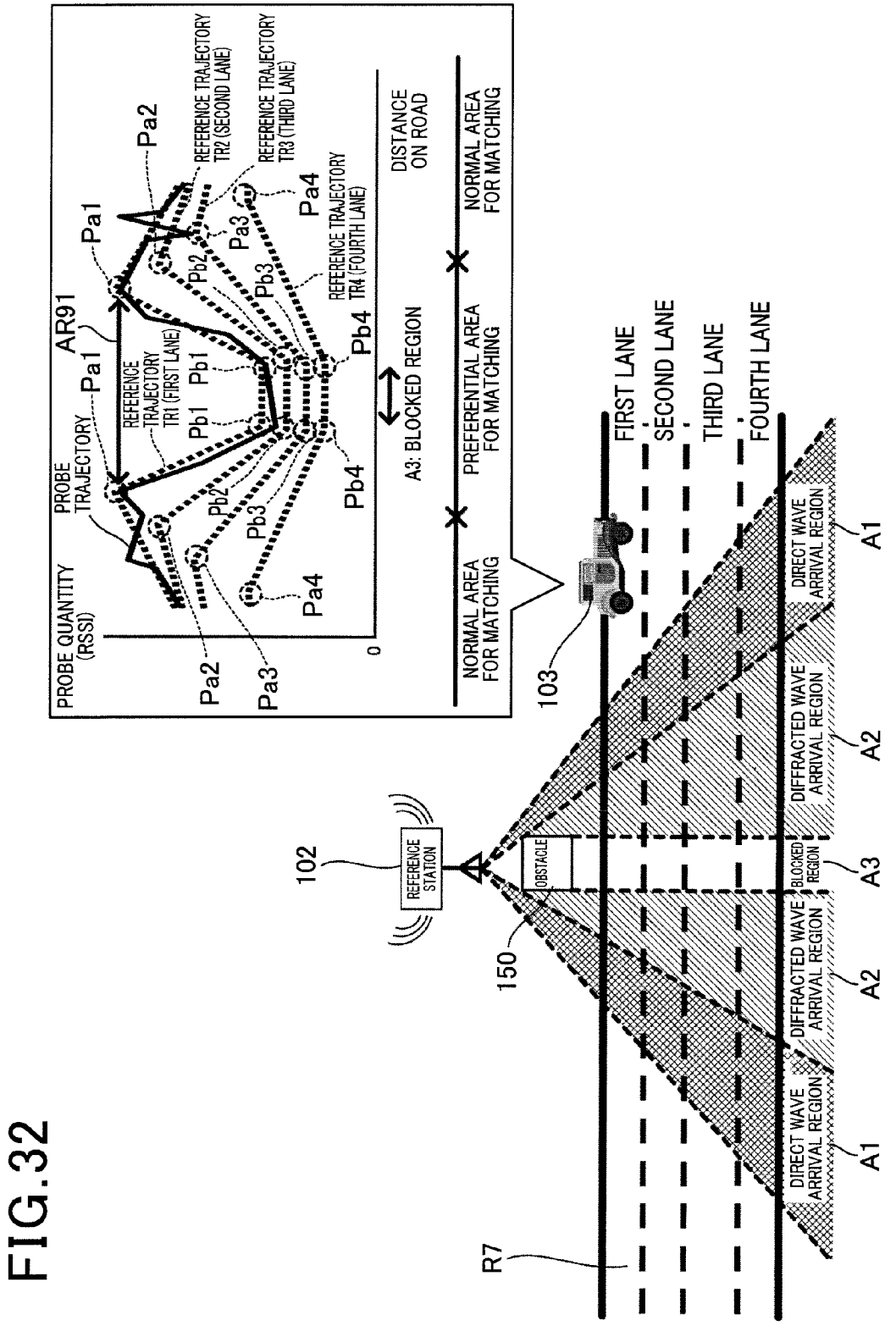

PROBE QUANTITY (RSSI)
PROBE TRAJECTORY
AR91
Pa1
Pa2
Pa3
Pa4
Pb1
Pb2
Pb3
Pb4
REFERENCE TRAJECTORY TR1 (FIRST LANE)
REFERENCE TRAJECTORY TR2 (SECOND LANE)
REFERENCE TRAJECTORY TR3 (THIRD LANE)
REFERENCE TRAJECTORY TR4 (FOURTH LANE)
DISTANCE ON ROAD
0
A3: BLOCKED REGION
NORMAL AREA FOR MATCHING
PREFERENTIAL AREA FOR MATCHING
NORMAL AREA FOR MATCHING
103
FIRST LANE
SECOND LANE
THIRD LANE
FOURTH LANE
DIRECT WAVE ARRIVAL REGION
DIFFRACTED WAVE ARRIVAL REGION
BLOCKED REGION
OBSTACLE
A1
A2
A3
150
102
REFERENCE STATION
R7

FIG.33

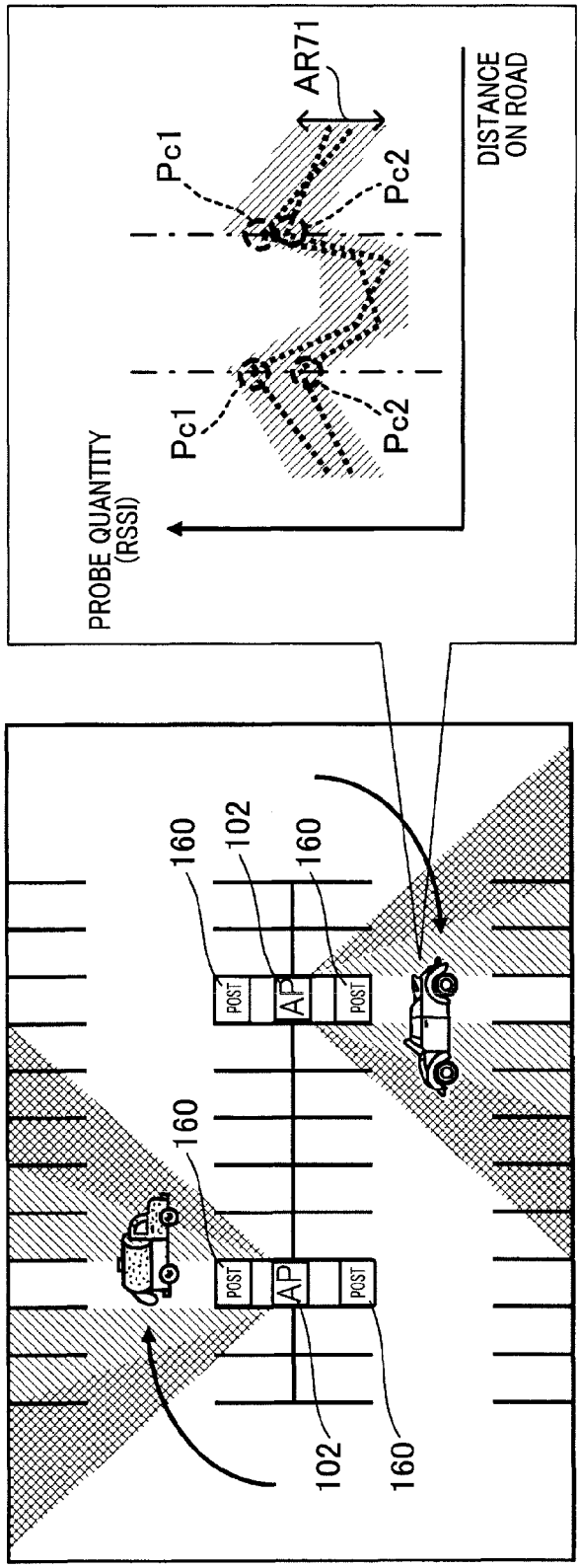

AR71
Pc1
Pc2
Pc1
Pc2
DISTANCE ON ROAD
PROBE QUANTITY (RSSI)
160
102
160
160
POST
AP
POST
POST
AP
POST
102
160

FIG.34

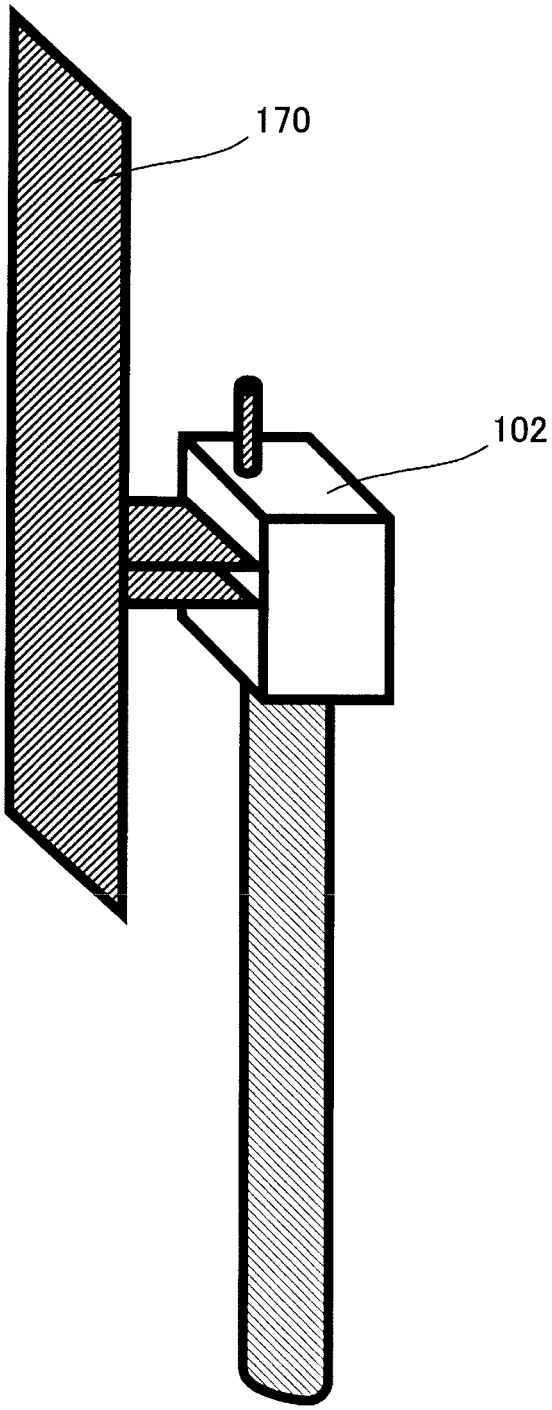
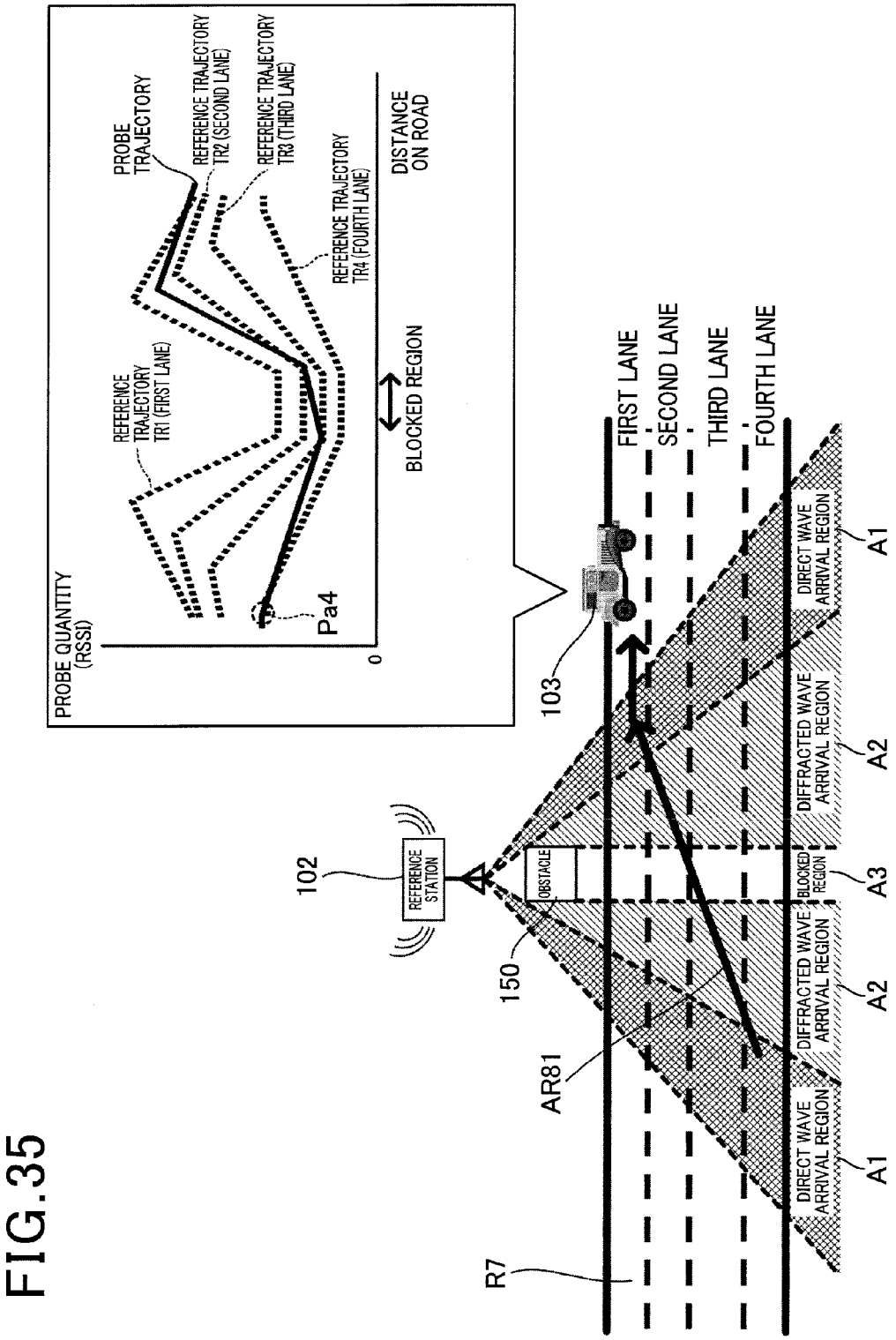


FIG.35


PROBE QUANTITY (RSSI)
PROBE TRAJECTORY
REFERENCE TRAJECTORY TR2 (SECOND LANE)
REFERENCE TRAJECTORY TR3 (THIRD LANE)
REFERENCE TRAJECTORY TR4 (FOURTH LANE)
REFERENCE TRAJECTORY TR1 (FIRST LANE)
Pa4
0
DISTANCE ON ROAD
BLOCKED REGION
103
FIRST LANE
SECOND LANE
THIRD LANE
FOURTH LANE
102
REFERENCE STATION
OBSTACLE
150
AR81
R7
DIRECT WAVE ARRIVAL REGION
DIFFRACTED WAVE ARRIVAL REGION
BLOCKED REGION
A1
A2
A3

WIRELESS COMMUNICATION APPARATUS AND WIRELESS POSITIONING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

This application is based on and claims the benefit of priorities from earlier Japanese Patent Application No. 2012-114856 filed May 18, 2012 and Japanese Patent Application No. 2013-026586 filed Feb. 14, 2013, the descriptions of which are incorporated herein by reference.

BACKGROUND

1. Technical Field

The present invention relates to a wireless communication apparatus and a wireless positioning system, which perform positioning through wireless communication.

2. Related Art

GPS (global positioning system) is well known as a wide-area position information service. However, GPS suffers from a problem that, within buildings or behind doors, position information services are not available. Further, GPS, which relies on GPS satellite infrastructure, also suffers from a problem that infrastructure failure or service outage will disable use of the position information services.

Wireless LAN (local area network) positioning technique has been used for some time, which enables positioning not relying on a GPS satellite but using electrical measurement information of widespread wireless LAN. However, in the wireless LAN positioning technique, the positioning accuracy depends on the number of base stations that can receive signals and specify positions. Therefore, the wireless LAN positioning technique suffers from a problem of the cost of building the base stations involved in spreading the technique in a wide area.

In order to solve the problems as set forth above, infrastructure that makes it possible to provide wide-area position information services not relying on a GPS satellite has started to build (see, for example, JP-A-2008-104029). In this infrastructure, the information of detecting wireless LAN stations that are used for communication is aggregated in the cloud for cloud computing using computing resources provided as a service over a network. Then, the LAN stations can be used as base stations for position detection, thereby reducing the cost of building base stations. Thus, wide-area position information services not relying on a GPS satellite becomes available.

However, the technique of aggregating in cloud the information of detecting wireless LAN base stations as disclosed in JP-A-2008-104029 also suffers from a problem that the positioning accuracy greatly depends on the density of the registered base stations.

SUMMARY

The present invention provides a technique that enables positioning without relying on the density of the surrounding base stations.

According to a first aspect of the present disclosure, there is provided a wireless communication apparatus, including: wireless communicating means for receiving data transmitted from at least one wireless transmitter by direct wireless communication, the at least one wireless transmitter transmitting data in a wireless manner; detecting means for detecting wireless reception condition in the wireless communicating means; reference information storing means for storing relation reference information (relation reference information) that sets two or more relations between (i) the wireless reception condition in the wireless communicating means on a reception condition of data transmitted from the wireless transmitter and (ii) location information (location related information) relating to a location of the wireless transmitter; distance measuring means for measuring relative distance information (relative distance related information) relating to a relative distance between the wireless transmitter and the wireless communication apparatus: first generating means for generating first relation information (first relation measurement information) indicating a relation between a plurality of the wireless reception conditions detected by the detecting means and a plurality of the relative distance information measured by the distance measuring means; relation determining means for determining a relation between the location information and the relative distance information by comparing the relation reference information and the first relation information; and position determining means for determining a current location of the wireless communication apparatus on the basis of (a) the relation between the location information and the relative distance information determined by the relation determining means and (b) a current wireless reception condition in the wireless communicating means detected by the detecting means.

The wireless communication apparatus configured in this way is able to perform direct wireless communication with one radio transmitter related to the relation reference information, thereby determining the current location of the wireless communication apparatus. Thus, positioning can be performed irrespective of the density of radio transmitters that are present around the wireless communication apparatus.

In the wireless communication apparatus, the wireless transmitter may be provided to be fixed to a predetermined installation position. The location information in the relation reference information may be information indicating a position on a road laid around the wireless transmitter. The relative distance information in the first relation information may be a travel distance (movement distance) of a vehicle provided with the wireless communication apparatus that moves on the road laid around the wireless transmitter.

When the wireless communication apparatus configured in this way moves on a road, the apparatus is able to perform direct wireless communication with one radio transmitter related to the relation reference information to thereby determine the location of the wireless communication apparatus on the road. This is because the radio transmitter is provided being fixed to a predetermined installation position. Accordingly, the apparatus is able to determine relation information (i.e., relation reference information) between wireless reception condition from the radio transmitter and the information that indicates the position on the road that is laid around the radio transmitter. It should be appreciated that "the current location in the wireless communication apparatus" set forth above corresponds to the "current location on the road in the wireless communication apparatus".

In the wireless communication apparatus, the wireless transmitter may be mounted in a first moving object that moves on a road. The location information in the relation reference information may be information indicating a relative distance between the first moving object and the wireless communication apparatus. The relative distance information in the first relation information may be information indicating an increase and decrease in a relative distance between the first moving object and the wireless communication apparatus with respect to a reference relative distance that is a

relative distance between the first moving object and the wireless communication apparatus at a predetermined time point.

When the wireless communication apparatus configured in this way moves near the first moving object, the apparatus is able to perform direct wireless communication with one radio transmitter (i.e. the radio transmitter installed in the first moving object) related to the relation reference information to thereby determine a relative distance between the first moving object and the wireless communication apparatus. It should be appreciated that, in this case, the "current location in the wireless communication apparatus" is the "current location with reference to the first moving object" and thus corresponds to the "relative distance between the first moving object and the wireless communication apparatus".

According to a second aspect of the present disclosure, there is provided a wireless positioning system, including: the wireless transmitter as described above and the wireless communication apparatus as described above. The wireless positioning system configured in this way includes the wireless communication apparatus recited in claim **1** and thus can exert effects similar to those of the wireless communication apparatus recited in claim **1**.

BRIEF DESCRIPTION OF DRAWINGS

In the accompanying drawings:

FIG. **1** is a diagram illustrating a configuration of a wireless positioning system according to a first embodiment of the present invention;

FIG. **2** is a block diagram illustrating a configuration of an on-vehicle apparatus in the wireless positioning system of FIG. **1**;

FIG. **3** is a block diagram illustrating a configuration of a management server in the wireless positioning system of FIG. **1**;

FIG. **4** is a flow diagram illustrating a position estimation process, according to the first embodiment;

FIG. **5** is a diagram illustrating a reference trajectory;

FIG. **6** is a diagram illustrating reference trajectories of inbound and outbound lanes;

FIG. **7** is an explanatory diagram illustrating a position determination method using a reference trajectory and a probe trajectory;

FIG. **8** is a flow diagram illustrating a trajectory update process, according to the first embodiment;

FIG. **9** is a diagram illustrating a specific example of position estimation, according to the first embodiment;

FIG. **10** is a diagram illustrating a configuration of a wireless positioning system according to a second embodiment of the present invention;

FIG. **11** is a block diagram illustrating a configuration of a reference station in the wireless positioning system of FIG. **10**;

FIG. **12** is a block diagram illustrating a configuration of an on-vehicle apparatus **103** in the wireless positioning system of FIG. **10**;

FIG. **13** is a flow diagram illustrating a position estimation process, according to the second embodiment;

FIG. **14** is a flow diagram illustrating a trajectory update process, according to the second embodiment;

FIG. **15** is a diagram illustrating a specific example of position estimation, according to the second embodiment;

FIG. **16** is a diagram illustrating a specific example of position estimation according to a third embodiment of the present invention;

FIG. **17** is a flow diagram illustrating a position estimation process, according to the third embodiment;

FIG. **18** is a flow diagram illustrating a trajectory update process, according to the third embodiment;

FIG. **19** is a flow diagram illustrating a position estimation process, according to a fourth embodiment of the present invention;

FIG. **20** is a flow diagram illustrating a trajectory update process, according to the fourth embodiment;

FIG. **21** is a diagram illustrating a specific example of position estimation, according to the fourth embodiment;

FIG. **22** is a diagram illustrating a configuration of a wireless positioning system according to a fifth embodiment of the present invention;

FIG. **23** is a block diagram illustrating a configuration of an on-vehicle apparatus in the wireless positioning system of FIG. **22**;

FIG. **24** is a block diagram illustrating a configuration of a management server in the wireless positioning system of FIG. **22**;

FIG. **25** is a flow diagram illustrating a position estimation process, according to the fifth embodiment;

FIG. **26** is a diagram illustrating an inter-vehicle distance reference trajectory;

FIG. **27** is a diagram illustrating an inter-vehicle distance probe trajectory;

FIG. **28** is a flow diagram illustrating a trajectory update process, according to the fifth embodiment;

FIG. **29** is a diagram illustrating a specific example of inter-vehicle distance estimation, according to the fifth embodiment;

FIG. **30** is a flow diagram illustrating a position estimation process, according to a sixth embodiment of the present invention;

FIG. **31** is a diagram illustrating a specific example of inter-vehicle distance estimation, according to the sixth embodiment;

FIG. **32** is a diagram illustrating a specific example of position estimation, according to a seventh embodiment of the present invention;

FIG. **33** is a two-dimensional diagram illustrating an indoor parking area in which an arrangement of a reference station is shown, according to another embodiment of the present invention;

FIG. **34** is a perspective diagram illustrating a configuration of a reference station, according to another embodiment of the present invention; and

FIG. **35** is a diagram illustrating a specific example of position estimation, according to another embodiment of the present invention.

DESCRIPTION OF EMBODIMENTS

With reference to the accompanying drawings, hereinafter are described several exemplary embodiments of the present invention.

First Exemplary Embodiment

First, a first exemplary embodiment of the present invention is described with reference to FIGS. **1** to **9**.

FIG. **1** is a diagram illustrating a configuration of a wireless positioning system **1** according to the first embodiment. As shown in FIG. **1**, the wireless positioning system **1** of the present embodiment includes a plurality of reference stations **2** (two reference stations **2***a* and **2***b* are shown in FIG. **1**), on-vehicle apparatuses **3** (three on-vehicle apparatuses **3***a*, **3***b*

and 3*c* are shown in FIG. **1**) and a management server **4**. The reference stations **2** are arranged being scattered in an out-of-service area of GPS (global positioning system) to perform direct wireless communication. The on-vehicle apparatuses **3** are each installed in a motorcar to perform direct wireless communication. The management server **4** manages data for measuring the position of each on-vehicle apparatus **3**.

The reference station **2** periodically transmits a radio beacon including identification information of the reference station **2** to the motorcars around it, using a direct wireless communication function. Of the plurality of reference stations **2***a*, **2***b* and **2***c*, some (the reference station **2***b* in FIG. **1**) are configured to perform data communication with the management server **4** via a wide-area wireless communication network NW (e.g., mobile phone communication network).

As shown in FIG. **2**, the on-vehicle apparatus **3** includes a vehicle speed sensor **11**, a position detector **12**, a direct wireless communication device **13**, wide-area wireless communication device **14** and a control unit **15**.

Of these components, the vehicle speed sensor **11** detects the speed of the vehicle that installs the vehicle sensor **11**. The detection results of the vehicle speed sensor **11** are inputted to the control unit **15**.

The position detector **12** is configured by a GPS receiver and a plurality of sensors. The GPS receiver receives a satellite signal transmitted from a GPS satellite. The plurality of sensors include, for example, a distance sensor that detects a travel distance (movement distance) of the vehicle that installs the on-vehicle apparatus **3** (hereinafter referred to as "the own vehicle") on the basis of the rotation of the own vehicle, and an azimuth sensor. Based on the signals obtained from these sensors, the position detector **12** detects the position and the travelling direction of the own vehicle. The detection results of the position detector **12** are inputted to the control unit **15**.

The direct wireless communication device **13** performs direct wireless communication with the reference station **2**.

The wide-area wireless communication device **14** performs data communication with the management server **4** via the wide-area wireless communication network NW.

The control unit **15** includes a central processing unit (CPU) **21**, a read-only memory (ROM) **22** and a random access memory (RAM) **23** and controls the communication devices **13** and **14** by allowing the CPU **21** to perform a process based on a program which is stored in the ROM **22**.

As shown in FIG. **3**, the management server **4** includes a wide-area wireless communication device **31** and a control unit **32**. Of these components, the wide-area wireless communication device **31** communicates with the reference station **2** and the on-vehicle apparatus **3** via the wide-area wireless communication network NW. The control unit **32** includes a CPU **41**, a ROM **42** and a RAM **43** and controls the wide-area wireless communication device **31** by allowing the CPU **41** to perform a process based on a program which is stored in the ROM **42**. The RAM **43** of the control unit **32** stores reference trajectory information (described later) regarding the plurality of reference stations **2**.

In the wireless positioning system **1** configured as described above, the on-vehicle apparatus **3** performs a position estimation process that will be described later. The management server **4** performs a trajectory update process that will be described later.

First, referring to FIG. **4**, hereinafter are described steps of the position estimation process performed by the CPU **21** of the on-vehicle apparatus **3**. The position estimation process is repeatedly performed while the CPU **21** is activated.

When the position estimation process is performed, the CPU **21** determines, first, at step S**10**, whether or not connection is established with the management server **4** so that the wide-area wireless communication device **14** can communicate with the management server **4**. If no connection is established with the management server **4** (NO at step S**10**), control proceeds to step S**40**. On the other hand, if connection is established with the management server **4** (YES at step S**10**), control proceeds to step S**20**.

At step S**20**, if there is a probe trajectory (described later) that has not been transmitted to the management server **4**, the CPU **21** transmits probe trajectory information indicating the untransmitted probe trajectory to the management server **4**, together with the identification information of the reference station **2** and the information indicating the type of the own vehicle, travelling direction (described later) and current time.

Then, at step S**30**, the CPU **21** acquires reference trajectory information from the management server **4**. The reference trajectory information indicates a reference trajectory of the reference station **2** which is present within a predetermined distance (e.g., 1 km in the present embodiment) from the current location, in the vicinity of the road on which the vehicle (own vehicle) provided with the on-vehicle apparatus **3** travels.

The acquired reference trajectory information is stored in the RAM **23**, and control proceeds to step S**40**. The reference trajectory information of the reference station **2** is provided for each vehicle type and for each travelling direction (see FIG. **6**). The travelling direction is used here for distinguishing travelling on an inbound lane and traveling on an outbound lane of the road.

Of a plurality of pieces of reference trajectory information regarding the reference stations **2**, the CPU **21** of the on-vehicle apparatus **3** acquires only the reference trajectory information regarding the vehicle type of the own vehicle and the travelling direction of the own vehicle from the management server **4**. However, if the reference trajectory information of the reference station **2** has been acquired in the past and the reference trajectory information has not been updated since the previous acquisition, no reference trajectory information is acquired.

The reference trajectory indicates a relation between travel distance and probe quantity (see FIG. **5**). The travel distance refers to a distance that the own vehicle has traveled on the road in the vicinity of the reference station **2** from a point nearest to the reference station **2** as a base point (hereinafter referred to as a reference travel distance).

The probe quantity is associated with the reference station **2** (in the present embodiment, the probe quantity refers to a received signal strength RSSI (received signal strength indicator) of a radio signal that the on-vehicle apparatus **3** has received from the reference station **2**). The probe quantity is maximized at a point nearest from the reference station **2** on the road, in the vicinity of the reference station **2**.

In the reference trajectory, the probe quantity does not necessarily gradually decrease as the own vehicle travels away from the point nearest to the reference station **2**. The reference trajectory may have a local maximal point (see the command ID**01** of FIG. **6**) reflecting the reflection or diffraction caused by a nearby building (see the arrow AL**00**).

When control proceeds to step S**40**, the CPU **21** determines whether or not a radio beacon has been detected. If no radio beacon has been detected (NO at step S**40**), this iteration of the position estimation process is ended. On the other hand, if a radio beacon has been detected (YES at step S**40**), control proceeds to step S**50**. At step S**50**, the CPU **21** detects a probe

quantity (the received signal strength RSSI in the present embodiment) of the detected radio beacon.

At the same time, at step S60, the CPU 21 calculates a travel distance of the own vehicle from the time point when the radio beacon has initially been detected (hereinafter is referred to a probe travel distance). Then, at step S70, a probe trajectory (see FIG. 7) is generated, which indicates a relation between probe quantity and probe travel distance from the time point when the radio beacon has initially been detected to the current time point.

Then, at step S80, the probe trajectory generated at step S70 is superimposed over the reference trajectory which is indicated by the reference trajectory information acquired at step S30 (see FIG. 7) to determine whether or not there is a matching portion therebetween, with a degree of matching equal to or more than a predetermined trajectory matching threshold.

If there is not a matching portion with a degree of matching equal to or more than the trajectory matching threshold (NO at step S80), the position estimation process is once ended. On the other hand, if there is a matching portion with a degree of matching equal to or more than the trajectory matching threshold (YES at step S80), control proceeds to step S90.

At step S90, the CPU 21 calculates a travel distance TD from an arbitrary characteristic point CP on the reference trajectory to the current time point (see FIG. 7). The characteristic point CP corresponds, for example, to a maximal, minimal, local maximal or local minimal point of the probe quantity.

Then, at step S100, the CPU 21 calculates a current location of the own vehicle on the road the own vehicle travels, on the basis of the travel distance TD from the characteristic point CP to the current time point. Then, the position estimation process is once ended.

Referring now to FIG. 8, hereinafter are described steps of the trajectory update process performed by the CPU 41 of the management server 4. The trajectory update process is repeatedly performed while the CPU 41 is activated.

When the trajectory update process is performed, the CPU 41 determines, first, at step S210, whether or not probe trajectory information has been received from the on-vehicle apparatus 3. If no probe trajectory information has been received (NO at step S210), the trajectory update process is once ended. On the other hand, if probe trajectory information has been received (YES at step S210), control proceeds to step S220.

At step S220, the received probe trajectory information is classified and stored on the basis of the identification information of the reference station 2, the vehicle type of the vehicle that installs the on-vehicle apparatus 3, and the travelling direction of the vehicle (travelling direction in the inbound lane, or travelling direction in the outbound lane).

Then, at step S230, the reference trajectory having the same reference station, vehicle type and travelling direction as those of the probe trajectory information added at step S220 is updated using the probe trajectory added at step S220. Then, the trajectory update process is once ended.

Specifically, in the present embodiment, for example, the probe trajectories stored up to then are classified on the basis of the same reference station, the same vehicle type and the same travelling direction. Then, an average value is calculated for the probe trajectories of each classification and the average value is used as a reference trajectory. However, an average value is calculated after removing those probe trajectories which have a variance equal to or more than a predetermined removal threshold.

Referring to FIG. 9, hereinafter is described a specific example of position estimation performed in the wireless positioning system 1 configured as described above.

As shown in FIG. 9, the reference stations 2*a* and 2*b* are set up along a road R1. The reference stations 2*a* and 2*b* are arranged at an interval that an autonomous sensor of a vehicle can interpolate it with sufficient accuracy. The reference station 2*a* is not connected to the management server 4 via the wide-area wireless communication network NW, while the reference station 2*b* is connected to the management server 4 via the wide-area wireless communication network NW.

A vehicle that has the on-vehicle apparatus 3*a* (hereinafter referred to as first vehicle) travels on the road R1 toward the reference station 2*a*. A vehicle that installs the on-vehicle apparatus 3*b* (hereinafter referred to as second vehicle) travels on the road R1 away from the reference station 2*a* toward the reference station 2*b*. A vehicle that installs the on-vehicle apparatus 3*c* (hereinafter referred to as third vehicle) travels on the road R1 away from the reference station 2*b*.

The first vehicle that travels toward the reference station 2*a* acquires, from the management server 4, reference trajectory information of the reference station 2*a* regarding vehicle type and travelling direction which are the same as those of the first vehicle (see the arrow AL01).

The second vehicle that travels near the reference station 2*a* generates a probe trajectory in relation to the reference station 2*a* and calculates the current location of the second vehicle on the basis of the results of matching between the generated probe trajectory and the reference trajectory of the reference station 2*a*.

The third vehicle travels near the reference station 2*b* that enables connection to the management server 4. If the third vehicle is connected to the management server 4 via the reference station 2*b*, the third vehicle transmits the untransmitted probe trajectory information to the management server 4 via the reference station 2*b* (see the arrow AL02).

In the on-vehicle apparatus 3 configured in this way, the direct wireless communication device 13 receives data transmitted via radio from the reference station 2 by performing direct wireless communication and then the direct wireless communication device 13 detects the received signal strength RSSI (step S50). Further, the RAM 23 stores reference trajectory information.

In the reference trajectory information, two or more points of relation between the received signal strength RSSI and travel distance are set. The received signal strength RSSI is a signal strength at the time when the direct wireless communication device 13 receives data, via radio, transmitted from the reference station 2. The travel distance is a distance that the own vehicle has traveled from a point, i.e. a base point, nearest from the reference station 2, on the road in the vicinity of the reference station 2 (the distance is the reference travel distance mentioned above and corresponds to the position on the road).

Further, the position detector 12 calculates a travel distance of the own vehicle from the time point when a radio beacon has initially been detected (probe travel distance) (step S60). Then, probe trajectory information is generated, which indicates a relation between a plurality of received signal strengths RSSI of the direct wireless communication device 13 and a plurality of probe travel distances (step S70).

Then, the reference trajectory information and the probe trajectory information are compared to determine a relation between the reference travel distance and the probe travel distance (step S80). Then, the current location in the on-vehicle apparatus 3 is determined on the basis of the relation between the reference trajectory information and the probe

trajectory information, and the currently detected received signal strength RSSI (steps **S90** and **S100**).

Thus, the current location of the on-vehicle apparatus **3** can be determined by performing direct wireless communication with one reference station **2** corresponding to the reference trajectory information.

Therefore, positioning is performed without depending on the density of the reference stations **2** around the on-vehicle apparatus **3**. This is because each reference station **2** is fixedly set up at a predetermined setting position and because the relation can be set between the condition (wireless reception condition) of receiving data via radio from the reference station **2** and the information (i.e., reference trajectory information) that indicates the position on the road built in the vicinity of the reference stations **2**.

Reference trajectory information is provided for each vehicle type of the vehicle that installs the on-vehicle apparatus **3**. Thus, when the probe quantity (the received signal strength RSSI in the present embodiment) changes depending on vehicle type, the positioning accuracy is prevented from being greatly varied depending on vehicle type.

Further, reference trajectory information is acquired from the management server **4** by performing wireless communication, via the wide-area radio communication network NW, with the management server **4** that manages reference trajectory information provided for each of the plurality of reference stations **2** (step **S30**). Thus, the on-vehicle apparatus **3** no longer requires to store, in advance, a number of pieces of reference trajectory information provided for the respective reference stations **2**. Accordingly, the on-vehicle apparatus **3** can acquire, as necessary, a few pieces of reference trajectory information from the management server **4**, from among the number of pieces of trajectory information, thereby saving the data storage area of the on-vehicle apparatus **3**.

Generated probe trajectory information is transmitted to the management server **4** by performing wireless communication via the wide-area wireless communication network NW (step **S20**). Thus, the management server **4** that manages reference trajectory information is able to update the reference trajectory information using the newly acquired probe trajectory information.

In the embodiment described above, the on-vehicle apparatus **3** is the wireless communication apparatus of the present invention. Likewise, the reference station **2** is the radio transmitter; the direct wireless communication device **13** is the radio communicating means or unit; step **S50** is the detecting means or unit; the RAM **23** is the reference information storing means or unit; step **S60** is the distance measuring means; step **S70** is the first generating means or unit; step **S80** is the relation determining means or unit; and steps **S90** and **S100** are the position determining means or unit.

Further, the received signal strength RSSI is the radio reception condition of the present invention. Likewise, the "travel distance that the own vehicle has traveled from a point, i.e. a base point, nearest from the reference station **2**, on the road in the vicinity of the reference station **2**" is the location information (location related information); the reference trajectory information is the relation reference information (relation reference information); the probe travel distance is the relative distance information (relative distance related information); and the probe trajectory information is the first relation information (first relation measurement information).

Furthermore, step **S30** is the second reference information acquiring means or unit. Likewise, step **S20** is the second measurement information transmitting means or unit; and the management server **4** is the first management apparatus.

Second Exemplary Embodiment

Next, a second exemplary embodiment of the present invention is described with reference to FIGS. **10** to **15**.

FIG. **10** is a diagram illustrating a configuration of a wireless positioning system **101**, according to the second embodiment.

As shown in FIG. **10**, the wireless positioning system **101** of the present embodiment includes a plurality of reference stations **102** (two reference stations **102***a* and **102***b* are shown in FIG. **10**) and on-vehicle apparatuses **103** (three on-vehicle apparatuses **103***a*, **103***b* and **103***c* are shown in FIG. **10**). The reference stations **102** are arranged being scattered in an out-of-service area of GPS (global positioning system) to perform direct wireless communication. The pm-vehicle apparatuses **3** are each installed in a motorcar to perform direct wireless communication.

The reference station **102** periodically transmits a radio beacon including identification information of the reference station **102** to the motorcars around it, using a direct wireless communication function.

As shown in FIG. **11**, each reference station **102** includes a direct wireless communication device **111** and a control unit **112**. Of these components, the direct wireless communication device **111** performs direct wireless communication with the on-vehicle apparatus **103**. The control unit **112** includes a CPU **121**, a ROM **122** and a RAM **123**. The control unit **112** controls the direct wireless communication device **111** by allowing the CPU **121** to perform a process which is based on a program stored in the ROM **122**. In the RAM **123** of the control unit **112**, reference trajectory information regarding the reference station **102** that installs this control unit **112** is classified and stored on the basis of vehicle type and travelling direction of vehicles.

As shown in FIG. **12**, the on-vehicle apparatus **103** includes a vehicle speed sensor **131**, a position detector **132**, a direct wireless communication device **133** and a control unit **134**. Of these components, the vehicle sensor **131**, the position detector **132** and the direct wireless communication device **133** are the same as the vehicle speed sensor **11**, the position detector **12** and the direct wireless communication device **13**, respectively, of the first embodiment. Therefore, description of these components is omitted. The control unit **134** includes a CPU **141**, a ROM **142** and a RAM **143** and controls the direct wireless communication **133** by allowing the CPU **141** to perform a program stored in the ROM **142**.

In the wireless positioning system **101** configured as described above, the on-vehicle apparatus **103** performs a position estimation process that will be described later. The reference station **102** performs a trajectory update process that will be described later.

First, referring to FIG. **13**, hereinafter are described steps of the position estimation process performed by the CPU **141** of the on-vehicle apparatus **103**. The position estimation process is repeatedly performed while the CPU **141** is activated.

When the position estimation process is performed, the CPU **141** determines, first, at step **S310**, whether or not a radio beacon has been detected. If no radio beacon has been detected (NO at step **S310**), control proceeds to step **S410**. On the other hand, if a radio beacon has been detected (YES at step **S310**), control proceeds to step **S320**.

At step **S320**, it is determined whether or not the reference station **102** specified by identification information included in the radio beacon is the one whose reference trajectory has not

been yet acquired by the on-vehicle apparatus **103**. If the reference station **102** is the one whose reference trajectory has already been acquired (NO at step S**320**), control proceeds to step S**340**.

On the other hand, if the reference station **102** is the one whose reference trajectory has been unacquired (YES at step S**320**), control proceeds to step S**330**. At step S**330**, the CPU **141** transmits a request for transmitting reference trajectory information (hereinafter referred to as reference trajectory request command) to the reference station **102** corresponding to the detected radio beacon.

In transmitting the reference trajectory request command, information on the vehicle type of the vehicle that installs the on-vehicle apparatus **103** (hereinafter referred to as "the own vehicle") and information on the travelling direction of the own vehicle are also transmitted. Then, control proceeds to step S**340**. At step S**340**, a probe quantity (received signal strength RSSI in the present embodiment) of the detected radio beacon is detected.

At the same time, at step S**350**, the CPU **141** calculates a travel distance (probe travel distance) of the own vehicle from the time point when the radio beacon has initially been detected. Then, at step S**360**, a probe trajectory (see FIG. **6**) is generated, which indicates a relation between probe quantity and probe travel distance from the time point when the radio beacon has initially been detected up to the current time point.

Then, at step S**370**, if the reference trajectory information corresponding to the detected radio beacon has already been acquired, the probe trajectory generated at step S**360** is superimposed over the reference trajectory indicated by the reference trajectory information (see FIG. **6**) to determine whether or not there is a matching portion, with a degree of matching equal to or more than a predetermined trajectory matching threshold.

If there is not a matching portion with a degree of matching equal to or more than the trajectory matching threshold (NO at step S**370**), control proceeds to step S**410**. On the other hand, if there is a matching portion with a degree of matching equal to or more than the trajectory matching threshold (YES at step S**370**), the CPU **141** calculates a travel distance TD (see FIG. **6**) from an arbitrary characteristic point CP on the reference trajectory to the current point.

Then, at step S**390**, based on the travel distance TD from the characteristic point CP to the current point, the CPU **141** calculates the current location of the own vehicle on the road the own vehicle travels. Further, at step S**400**, the CPU **141** transmits probe trajectory information indicating untransmitted probe trajectory to the reference station **102** corresponding to the detected radio beacon, together with the information indicating the vehicle type of the own vehicle, the travelling direction of the own vehicle and the current time. Then, control proceeds to step S**410**.

At step S**410**, it is determined whether or not reference trajectory information has been received from the reference station **102** corresponding to the detected radio beacon. If reference trajectory information has not been received (NO at step S**410**), the position estimation process is once ended. On the other hand, if the reference trajectory information has been received (YES at step S**410**), control proceeds to step S**420**. At step S**420**, the received reference trajectory information is stored in the RAM **143** and the position estimation process is once ended.

Referring to FIG. **14**, hereinafter are described steps of the trajectory update process performed by the CPU **121** of the reference station **102**. The trajectory update process is repeatedly performed while the CPU **121** is activated.

When the trajectory update process is performed, the CPU **121** determines, first, at step S**510**, whether or not a reference trajectory request command has been received from the on-vehicle apparatus **103**. If the reference trajectory request command has not been received (NO at step S**510**), control proceeds to step S**530**. On the other hand, if the reference trajectory request command has been received (YES at step S**510**), control proceeds to step S**520**.

At step S**520**, the CPU **121** transmits reference trajectory information to the on-vehicle apparatus **103**. The reference trajectory information includes a reference trajectory having the vehicle type and the travelling direction that are specified by the vehicle type information and the travelling direction information, respectively, received together with the reference trajectory request command. Then, control proceeds to step S**530**.

At step S**530**, the CPU **121** determines whether or not probe trajectory information has been received from the on-vehicle apparatus **103**. If probe trajectory information has not been received (NO at step S**530**), the trajectory update process is once ended. On the other hand, if probe trajectory information has been received (YES at step S**530**), control proceeds to step S**540**.

At step S**540**, the CPU **121** determines whether or not the received probe trajectory information is continuation information of a probe session in the past, which has been generated at step S**550** that will be described later. If the received probe trajectory information is not the continuation information (NO at step S**540**), control proceeds to step S**550** where a new probe session is generated.

The probe session corresponds to a storage area provided for storing probe trajectory information which has been transmitted from a certain on-vehicle apparatus **103** to the reference station **102**, from when the on-vehicle apparatus **103** approaches the reference station **102** until when it moves away therefrom. The probe session is set with the vehicle type information and the travelling direction information, which correspond to the probe trajectory information received at step S**530**.

Then, at step S**560**, a session timer is activated and control proceeds to step S**580**. For example, the count of the session timer is incremented every 100 ms. When activated, the count is incremented from zero.

On the other hand, if the received probe trajectory information is continuation information (YES at step S**540**), control proceeds to step S**570** where the session timer is reactivated. Then, control proceeds to step S**580**.

At step S**580**, the received probe trajectory information is stored in the probe session. Then, at step S**590**, the CPU **121** determines whether or not the count of the session timer is equal to or larger a predetermined expiration threshold. In other words, the CPU **121** determines whether or not the elapsed time since previous reception of the probe trajectory information has exceeded the time corresponding to the expiration threshold.

If the count of the session timer is smaller than the expiration threshold (NO at step S**590**), the trajectory update process is once ended. On the other hand, if the count of the session timer is equal to or larger than the expiration threshold (YES at step S**590**), control proceeds to step S**600**.

At step S**600**, the probe trajectory information stored in the probe session is classified and stored in the RAM **123** on the basis of the vehicle type of vehicle installing the on-vehicle apparatus **103** and travelling direction of the vehicle (travelling direction in the inbound lane, or travelling direction in the outbound lane), according to the vehicle type information and the travelling direction information set in the probe session.

Then, at step S610, similar to step S230 of the first embodiment, the reference trajectory having a vehicle type and a travelling direction, which are the same as those of the probe trajectory information added at step S600, is updated using the probe trajectory added at step S600. Further, at step S620, the increment of the count of the session timer is stopped and then the trajectory update process is once ended.

Referring to FIG. 15, hereinafter is described a specific example of position estimation performed in the wireless positioning system 101 configured as described above.

As shown in FIG. 15, the reference stations 102*a* and 102*b* are set up along a road R2. The reference stations 102*a* and 102*b* are arranged at an interval that an autonomous sensor of a vehicle can interpolate it with sufficient accuracy.

A vehicle that installs the on-vehicle apparatus 103*a* (hereinafter referred to as first vehicle) travels on the road R2 toward the reference station 102*a*. A vehicle that installs the on-vehicle apparatus 103*b* (hereinafter referred to as second vehicle) travels on the road R2 away from the reference station 102*a* toward the reference station 102*b*.

When the first vehicle approaches the reference station 102*a* such that a radio beacon from the reference 102*a* can be detected, the first vehicle acquires reference trajectory information of the reference station 102*a*, regarding the vehicle type and the travelling direction which are the same as those of the first vehicle (see the arrow AL11). Also, the first vehicle transmits untransmitted probe trajectory information to the reference station 102*a* (see the arrow AL12).

The second vehicle, which is travelling near the reference station 102*a*, generates a probe trajectory in relation to the second reference station 102*a* and calculates the current location of the second vehicle on the basis of the results of matching between the generated probe trajectory and the reference trajectory of the reference station 102*a*. At the same time, the second vehicle transmits untransmitted probe trajectory information to the reference station 102*a* (see the arrow AL13).

In the on-vehicle apparatus 103 configured as described above, reference trajectory information transmitted from the reference station 102 is acquired using the direct wireless communication device 133 (steps S320, S330, S410 and S420). Thus, the reference trajectory information is acquired without using a communication device that performs wireless communication via the wide-area wireless communication network NW.

Further, using the direct wireless communication device 133, generated probe trajectory information is transmitted to the reference station 102 (step S400). Thus, the reference station 102, in which reference trajectory information is stored, updates the reference trajectory information using the newly acquired probe trajectory information.

In the embodiment described above, the on-vehicle apparatus 103 is the wireless communication apparatus of the present invention. Likewise, the reference station 102 is the radio transmitter; the direct wireless communication device 133 is the radio communicating means or unit; step S340 is the detecting means or unit; the RAM 143 is the reference information storing means or unit; step S350 is the distance measuring means or unit; step S360 is the first generating means or unit; step S370 is the relation determining means or unit; and steps S380 and S390 are the position determining means or unit.

Steps S320, S330, S410 and S420 are the first reference information acquiring means or unit. Likewise, step S400 is the first measurement information transmitting means or unit.

Third Exemplary Embodiment

Next, a third exemplary embodiment of the present invention is described with reference to FIGS. 16 to 18.

In the third embodiment, only the differences from the second embodiment are described. Also, in the third embodiment, the components identical with or similar to those in the second embodiment are given the same reference numerals for the sake of omitting unnecessary explanation.

As shown in FIG. 16, the wireless positioning system 101 of the third embodiment is different from the second embodiment in that the reference stations 102*a* and 102*b* are set up along a road R3 having two lanes each way, and the position estimation process and the trajectory update process are changed. The remaining configuration is similar to that of the second embodiment.

In the RAM 123 of the control unit 112, pieces of reference trajectory information regarding the reference station 102 that installs the control unit 112 are classified and stored on the basis of vehicle type and traveling direction of vehicles. Each piece of reference trajectory information includes a reference trajectory of each of first and second lanes configuring the two lanes of each way (see the reference trajectories TR1 and TR2 in FIG. 16).

As shown in FIG. 17, in the position estimation process according to the third embodiment, step S360 and steps S380 to S400 are omitted and steps S710 to S750 are added. The remaining steps are similar to those of the second embodiment.

Specifically, after finishing step S350, control proceeds to step S710. At step S710, the CPU 141 of the on-vehicle apparatus 103 generates a probe trajectory (see FIG. 6), which indicates a relation between probe quantity and probe travel distance from the time point when a radio beacon has initially been detected up to the current time point. The probe quantity additionally includes the speed and the steering angle of the own vehicle at the time point when the probe quantity has been detected. When step S710 is finished, control proceeds to step S370.

At step S370, if there is a matching portion with a degree of matching equal to or more than the trajectory matching threshold (YES at step S370), control proceeds to step S720.

At step S720, the lane corresponding to the reference trajectory that includes the matching portion with a degree of matching equal to or more than the trajectory matching threshold is set as a lane on which the own vehicle travels currently.

Then, at step S730, the CPU 141 calculates a travel distance TD from an arbitrary characteristic point CP to the current time point on the reference trajectory that corresponds to the set lane.

Then, at step S740, the CPU 141 calculates the current location of the own vehicle on the road on which the own vehicle travels, on the basis of the travel distance TD from the characteristic point CP to the current time point.

Then, at step S750, the CPU 141 transmits probe trajectory information indicating an untransmitted probe trajectory to the reference station 102 corresponding to the detected radio beacon, together with the information indicating the vehicle type and travel direction of the own vehicle and current time. Then, control proceeds to step S410.

As shown in FIG. 18, in the trajectory update process of the third embodiment, step S610 is omitted and step S810 is added. The remaining steps are similar to those of the second embodiment.

Specifically, when step S600 is finished, control proceeds to step S810. At step S810, similar to step S230 of the first

embodiment, the CPU **121** of the reference station **102** updates the reference trajectory having the vehicle type and travelling direction which are the same as those of the probe trajectory information added at step S**600**, using the probe trajectory added at step S**600**. However, the reference trajectory having the same vehicle type and travelling direction includes the reference trajectory of the first lane and the reference trajectory of the second lane.

Accordingly, at step S**810**, the CPU **121** determines whether the reference trajectory corresponds to the probe trajectory of the first lane or the probe trajectory of the second lane, on the basis of the speed information and the steering angle information added to the probe quantity of the probe trajectory, thereby updating the reference trajectory. When step S**810** is finished, control proceeds to step S**620**.

In the on-vehicle apparatus **103** configured as described above, reference trajectory information is provided for each lane of the road R**3**. Thus, by comparing the reference trajectory information provided for each lane of the road R**3** with the probe trajectory information, the lane on which the vehicle installing the on-vehicle apparatus **103** (the own vehicle) travels can be specified.

Fourth Exemplary Embodiment

Next, a fourth exemplary embodiment of the present invention is described with reference to FIGS. **19** to **20**.

The fourth embodiment is described focusing on the differences from the first embodiment. Also, in the fourth embodiment, the components identical with or similar to those in the first embodiment are given the same reference numerals for the sake of omitting unnecessary explanation.

The wireless positioning system **1** of the fourth embodiment is similar to that of the first embodiment except that the position estimation process and the trajectory update process are changed.

First, as shown in FIG. **19**, in the position estimation process according to the fourth embodiment, step S**20** is omitted but, instead, step S**900** is added. The remaining steps are similar to those of the first embodiment.

Specifically, when step S**10** is finished, control proceeds to step S**900**. At step S**900**, if there is any probe trajectory not yet transmitted to the management server **4**, the CPU **21** of the on-vehicle apparatus **3** transmits probe trajectory information indicating an untransmitted probe trajectory to the management server **4**, together with identification information of the reference station **2** and the information indicating the vehicle type and travelling direction of the own vehicle and current time.

Further, the CPU **21** transmits travel trajectory information to the management server **4**. The travel trajectory information indicates a travel trajectory that the own vehicle has traveled in a period including the period corresponding to the untransmitted probe trajectory and periods before and after the period of the untransmitted probe trajectory. When step S**900** is finished, control proceeds to step S**30**.

In the trajectory update process of the fourth embodiment, steps S**210** to S**230** are omitted but, instead, steps S**910** to S**960** are added. The remaining steps are similar to those of the first embodiment.

Specifically, when the trajectory update process is performed, the CPU **41** of the management server **4** determines, first, at step S**910**, whether or not probe trajectory information and travel trajectory information have been received from the on-vehicle apparatus **3**.

If the probe trajectory information and the travel trajectory information have not been received (NO at step S**910**), the trajectory update process is once ended. On the other hand, if the probe trajectory information and the travel trajectory information have been received (YES at step S**910**), control proceeds to step S**920**.

At step S**920**, the CPU **41** determines whether or not the received probe trajectory information is about the reference station already registered. Specifically, if the identification information of the reference station **2** is added to the probe trajectory information, the CPU **41** determines that the probe trajectory information is about the reference station already registered.

If the identification information of the reference station **2** is not added to the probe trajectory information, the CPU **41** makes a determination by comparing the reference trajectory information stored in the management server **4** with the received probe trajectory information and travel trajectory information.

If the received probe trajectory information is about the reference station already registered (YES at step S**920**), control proceeds to step S**930**. At step S**930**, the received probe trajectory information is classified and stored on the basis of the identification information of the reference station, the vehicle type of the vehicle that installs the on-vehicle apparatus **3**, and the travelling direction of the vehicle.

Then, at step S**940**, the CPU **41** updates the reference trajectory having the same reference station, vehicle type and travelling direction as those of the added probe trajectory information, using the probe trajectory added at step S**930**. Then, the trajectory update process is once ended.

On the other hand, if the received probe trajectory information is not about the reference station already registered (NO at step S**920**), control proceeds to step S**950**. At step S**950**, identification information of the reference station is newly allocated to the received probe trajectory information and travel trajectory information, followed by classifying and storing the probe trajectory information and the travel trajectory information on the basis of the identification information of the reference station, the vehicle type of the vehicle that installs the on-vehicle apparatus **3** and the travelling direction of the vehicle.

Then, at step S**960**, a reference trajectory is newly generated on the basis of the received probe trajectory information and travel trajectory information, followed by classifying and storing the reference trajectory on the basis of the identification information of the reference station, the vehicle type of the vehicle and the travelling direction of the vehicle. Then, the trajectory update process is once ended.

Referring now to FIG. **21**, hereinafter is described a specific example in which a reference trajectory is newly registered in the wireless positioning system **1** configured as described above.

As shown in FIG. **21**, a vehicle installing the on-vehicle apparatus **3***a* (hereinafter referred to as first vehicle) travels on a road R**4** and turns to the left at a cross-point CP of the road R**4** (see the travel trajectory VP**41**). At a position along the road R**4** short of the cross-point CP, an unregistered reference station **2***d* is set up.

The first vehicle, when travelling along the road R**4** and near the reference station **2***d*, is able to detect a radio beacon from the reference station **2***d* to thereby generate a probe trajectory PT**41** (see FIG. **21**).

The management server **4**, upon reception of the probe trajectory information indicating the probe trajectory TP**41** and the travel trajectory indicating the travel trajectory VP**41**, determines the point of the left turn on the travel trajectory VP**41** as being the position of a cross-point.

Then, using a position P41 of the cross-point as a reference, the management server 4 is able to specify a position P42 (characteristic point CP42) on the road R4, at which probe quantity is maximized in the probe trajectory PT41.

Thus, the management server 4 is able to newly register a reference trajectory that indicates a relation between probe quantity and position on the road R4, as a reference trajectory ST41 of the reference station 2*d* (see FIG. 21).

After the reference trajectory ST40 of the reference station 2*d* has been registered, a vehicle installing the on-vehicle apparatus 3*b* (hereinafter referred to as second vehicle) travels on the road R4 and goes straight on the cross-point CS of the road R4 (see the travel trajectory VP42).

In this case, the on-vehicle apparatus 3*b* compares probe trajectory information that indicates a probe trajectory PT42 (see FIG. 2) generated using a radio beacon from the reference station 2*d*, with the reference trajectory ST41 of the reference station 2*d* to thereby specify the position P42 on the road R4, at which the probe quantity is maximized. After that, the on-vehicle apparatus 3*b* acquires a travel distance VE41 from the position 42 using an autonomous sensor to thereby estimate a current location 43 (see FIG. 21) on the road R4.

A WAN (wide area network) base station WS (see FIG. 21), which is not power controlled, can also be registered as a reference station.

The on-vehicle apparatus 3 configured as described above transmits travel trajectory information corresponding to probe trajectory information to the management server 4 (step S900). Thus, the management server 4 is able to generate a reference trajectory that indicates a relation between probe quantity and position on the road R4, on the basis of the received probe trajectory information and travel trajectory information. Therefore, the reference trajectory information of the reference station 2 which is not registered in the management server 4 can be newly registered.

In the embodiment described above, step S900 is the travel trajectory transmitting means or unit. Likewise, the travel trajectory information is the movement trajectory information.

Fifth Exemplary Embodiment

Next, a fifth exemplary embodiment of the present invention is described with reference to FIGS. 22 to 29.

As shown in FIG. 22, a wireless positioning system 201 of the present embodiment includes a plurality of reference stations 202 (two reference stations 202*a* and 202*b* are shown in FIG. 22), an on-vehicle apparatus 203 (three on-vehicle apparatuses 203*a*, 203*b* and 203*c* are shown in FIG. 22) and a management server 204. The plurality of reference stations 202 are set up, being scattered along a road. The on-vehicle apparatus 203 is installed in a vehicle to perform direct wireless communication. The management server 204 manages data for measuring an inter-vehicle distance.

The reference station 202 periodically transmits a radio beacon including identification information of the reference station 202 to the vehicles around it, using a direct wireless communication function. Also, the plurality of reference stations 202 are each configured to perform data communication with the management server 204 via a wide-area wireless communication network NW (e.g., mobile phone communication network).

As shown in FIG. 23, the on-vehicle apparatus 203 includes a vehicle speed sensor 11, position detector 12, direct wireless communication device 213, wide-area wireless communication device 214, radar device 215 and control unit 216.

Of these components, the direct wireless communication device 213 performs direct wireless communication with the reference station 202 and the on-vehicle apparatus 203 of some other vehicle.

The wide-area wireless communication device 214 performs data communication with the management server 204 via the wide-area wireless communication network NW.

The radar device 215 transmits radar waves of a millimeter wave band in a forward direction of the vehicle that installs the on-vehicle apparatus 203 (hereinafter referred to as "the own vehicle") and receives reflected radar waves to detect a distance to a point at which the radar waves have been reflected.

The control unit 216 includes a CPU 221, ROM 222 and RAM 223. The control unit 216 allows the CPU 221 to execute a program stored in the ROM 222 to thereby control the communication devices 213 and 214 and the radar device 215.

The control unit 216 performs control under which the information that indicates the vehicle type and the speed of vehicle is mutually transmitted/received between the on-vehicle apparatus 203 of the own vehicle and the on-vehicle apparatus 203 of some other vehicle, using direct wireless communication.

As shown in FIG. 24, the management server 204 includes a wide-area wireless communication device 231 and a control unit 232.

Of these components, the wide-area wireless communication device 231 performs data communication with the reference station 202 and the on-vehicle apparatus 203 via the wide-area wireless communication network NW.

The control unit 232 includes a CPU 241, ROM 242 and RAM 243. The control unit 232 allows the CPU 241 to perform a process on the basis of a program stored in the ROM 242 to thereby control the wide-area wireless communication device 231. Also, the RAM 243 of the control unit 232 stores reference trajectory information regarding inter-vehicle distance (described later).

Hereinafter, the reference trajectory information regarding inter-vehicle distance is referred to as inter-vehicle distance reference trajectory information. The inter-vehicle distance reference trajectory information is provided for each combination of the vehicle type of the own vehicle and the vehicle type of a preceding vehicle.

In the wireless positioning system 201 configured as described above, the on-vehicle apparatus 203 performs an inter-vehicle distance estimation process that will be described latter. The management server 204 performs a trajectory update process that will be described later.

First, referring to FIG. 25, hereinafter are described steps of the inter-vehicle distance estimation performed by the CPU 221 of the on-vehicle apparatus 203. The inter-vehicle distance estimation process is repeatedly performed while the CPU 221 is activated.

When the inter-vehicle distance estimation process is performed, the CPU 221 determines, first, at step S1010, whether or not a connection is established with the management server 204 by the wide-area wireless communication device 214 so as to enable data communication.

If no connection is established with the management server 204 (NO at step S1010), control proceeds to step S1040. On the other hand, if connection is established with the management server 204 (YES at step S1010), control proceeds to step S1020.

At step S1020, if there is a radar probe trajectory (described later) not yet transmitted to the management server 204, the CPU 221 transmits radar probe trajectory information, which

indicates an untransmitted radar probe trajectory, to the management server **4**, together with vehicle type information indicative of the vehicle type of the own vehicle and preceding vehicle type information indicative of the vehicle type of a preceding vehicle.

Then, at step **S1030**, the CPU **221** acquires unacquired or unupdated inter-vehicle distance reference trajectory information from the management server **204** and stores the information in the RAM **223**.

Then, control proceeds to step **S1040**. A reference trajectory related to an inter-vehicle distance (hereinafter referred to as inter-vehicle distance reference trajectory) indicates a relation of inter-vehicle distance to a preceding vehicle, with probe quantity of a radio beacon received from the preceding vehicle (see FIG. **26**). The inter-vehicle distance reference trajectory is provided for each combination of the vehicle type of the own vehicle and the vehicle type of a preceding vehicle.

At step **S1040**, the CPU **221** determines whether or not a radio beacon from the on-vehicle apparatus **203** of some other vehicle has been detected. If no radio beacon has been detected (NO at step **S1040**), control proceeds to step **S1120**. On the other hand if a radio beacon has been detected (YES at step **S1040**), control proceeds to step **S1050**. At step **S1050**, the probe quantity (received signal strength RSSI in the present embodiment) of the detected radio beacon is detected.

At the same time, at step **S1060**, the CPU **221** calculates an inter-vehicle distance between the own vehicle and the preceding vehicle with reference to the time point when the radio beacon has initially been detected (hereinafter referred to as probe inter-vehicle distance).

Then, at step **S1070**, the CPU **221** generates a probe trajectory (see FIG. **27**) that indicates a relation between probe quantity and probe inter-vehicle distance (hereinafter referred to as inter-vehicle distance probe trajectory).

The probe inter-vehicle distance is calculated on the basis of the information regarding the travelling speed of the own vehicle and the information regarding the travelling speed of the preceding vehicle that is acquired through direct wireless communication with the preceding vehicle.

For example, a radio beacon from the on-vehicle apparatus **203** of some other vehicle may be initially detected, and the inter-vehicle distance at this time is indicated by D**0** (see FIG. **27**) (corresponding to a predetermined time point).

Then, when the own vehicle decelerates or the preceding vehicle accelerates, the probe inter-vehicle distance becomes longer than D**0**, depending on the amount of change in the speed. Contrarily, when the own vehicle accelerates or the preceding vehicle decelerates, the inter-vehicle distance becomes shorter than D**0**, depending on the amount of change in the speed. However, since the value of D**0** is unknown, the probe quantity cannot be correlated to the actual inter-vehicle distance in the inter-vehicle distance probe trajectory.

Then, at step **S1080**, the CPU **221** measures an inter-vehicle distance between the own vehicle and the preceding vehicle using the radar device **215** (hereinafter referred to as radar inter-vehicle distance). Then, at step **S1090**, the CPU **221** generates a probe trajectory that indicates a relation between probe quantity and radar inter-vehicle distance (hereinafter referred to as radar probe trajectory).

After that, at step **S1100**, the CPU **221** extracts the inter-vehicle distance reference trajectory information that is specified by the combination of the vehicle type of the own vehicle and the vehicle type of the preceding vehicle, from among a plurality of pieces of inter-vehicle distance reference trajectory information already acquired.

Then, the CPU **221** superimposes the inter-vehicle distance probe trajectory generated at step **S1070** over the inter-vehicle distance reference trajectory indicated by the extracted inter-vehicle distance reference trajectory information to determine whether or not there is a matching portion with a degree of matching equal to or more than a preset trajectory match threshold.

If there is not a matching portion with a degree of matching equal to or more than the trajectory matching threshold (NO at step **S1100**), control proceeds to step **S1120**. On the other hand, if there is a matching portion with a degree of matching equal to or more than the trajectory matching threshold (YES at step **S1100**), control proceeds to step **S1110**.

At step **S1100**, the CPU **221** sets the value of D**0** on the basis of the results of the superimposition between the inter-vehicle distance reference trajectory and the inter-vehicle distance probe trajectory, thereby correlating the probe quantity with the actual inter-vehicle distance in the inter-vehicle distance probe trajectory. Thus, the actual inter-vehicle distance is determined on the basis of the current probe quantity, and then control proceeds to step **S1120**.

At step **S1120**, the CPU **221** determines whether or not a radio beacon from the reference station **202** has been detected. If no radio beacon from the reference station **202** has been detected (NO at step **S1120**), the inter-vehicle distance estimation process is once ended. On the other hand, if a radio beacon from the reference station **202** has been detected (YES at step **S1120**), control proceeds to step **S1130**.

At step **S1130**, the CPU **221** transmits information to the management server **204** via the reference station **202**. The information includes the information regarding the probe quantity of a radio beacon received from the on-vehicle apparatus **203** of some other vehicle (probe quantity information), the information regarding the current location of the own vehicle (own vehicle's current location information), the information regarding the vehicle type of the own vehicle (own vehicle's vehicle type information), the information regarding the vehicle type of the preceding vehicle (preceding vehicle's vehicle type information), and the information regarding the current time (current time information). Then, the inter-vehicle distance estimation process is once ended.

Referring to FIG. **28**, hereinafter are described steps of the trajectory update process performed by the CPU **241** of the management server **204**. The trajectory update process is repeatedly performed while the CPU **241** is activated.

When the trajectory update process is performed, the CPU **241** determines, first, at step **S1210**, whether or not radar probe trajectory information has been received from the on-vehicle apparatus **203**.

If no radar probe trajectory information has been received (NO at step **S1210**), control proceeds to step **S1240**. On the other hand, if radar probe trajectory information has been received from the on-vehicle apparatus **203** (YES at step **S1210**), the CPU **241** classifies the received radar probe trajectory information on the basis of the combination of the vehicle type of the own vehicle and the vehicle type of the preceding vehicle and stores the classified data in the RAM **243**.

Then, at step **S1230**, the CPU **241** updates the inter-vehicle distance reference trajectory in which the combination between the vehicle type of the own vehicle and the vehicle type of the preceding vehicle is the same as that of the radar probe trajectory information added at step **S1220**, on the basis of the radar probe trajectory information added at step **S1220**.

Then, control proceeds to step **S1240**. The update is carried out by statistically processing data on the basis of conditions

such as of the vehicle type of the own vehicle, the vehicle type of the preceding, the road curvature and the lane.

At step S1240, the CPU 241 determines whether or not probe quantity information has been received from the on-vehicle apparatus 203. If no probe quantity information has been received (NO at step S1240), the trajectory update process is once ended. On the other hand, if probe quantity information has been received from the on-vehicle apparatus 203 (YES at step S1240), control proceeds to step S1250.

At step S1250, the CPU 241 stores the received probe quantity information, together with the concurrently received own vehicle's current location information, own vehicle's vehicle type information, preceding vehicle's vehicle type information and current time information.

Then, at step S1260, the inter-vehicle distance reference trajectory is updated on the basis of the information stored at step S1250. Then, the trajectory update process is once ended. The update is carried out by statistically processing data on the basis of conditions such as of the vehicle type of the own vehicle, the vehicle type of the preceding, the road curvature and the lane.

Referring to FIG. 29, hereinafter is described a specific example of the inter-vehicle distance estimation performed in the wireless positioning system 201 configured as described above.

As shown in FIG. 29, a vehicle installing the on-vehicle apparatus 203*a* (hereinafter referred to as first vehicle) and a vehicle installing the on-vehicle apparatus 203*b* (hereinafter referred to as second vehicle) travel near the reference station 202*a*. The second vehicle travels ahead of the first vehicle, while direct wireless communication is performed therebetween (see the arrow AL51).

In this case, each of the on-vehicle apparatuses 203*a* and 203*b* transmits probe quantity information and the like to the management server 204 via the reference station 202*a* (see the arrows AL52, AL53 and AL54).

Further, a vehicle installing the on-vehicle apparatus 203*d* (hereinafter referred to as fourth vehicle) travels ahead of a vehicle installing the on-vehicle apparatus 203*c* (hereinafter referred to as third vehicle). No reference station 202 is set up in the vicinity of the third and fourth vehicles.

The third vehicle detects an inter-vehicle distance between the third and fourth vehicles using the radar device, while performing direct wireless communication with the fourth vehicle (see the arrow AL55). In this case, the on-vehicle apparatus 203*c* transmits probe trajectory information and the like to the management server 204 (see the arrow AL56).

Then, the management server 204 generates an inter-vehicle distance trajectory and updates the inter-vehicle distance trajectory using the probe quantity information, the probe trajectory information and the like received from the on-vehicle apparatus 203.

Further, a vehicle installing the on-vehicle apparatus 203*f* (hereinafter referred to as sixth vehicle) travels ahead of a vehicle installing the on-vehicle apparatus 203*e* (hereinafter referred to as fifth vehicle). No reference station 202 is set up in the vicinity of the fifth and sixth vehicles.

Direct wireless communication is performed between the fifth and sixth vehicles (see the arrow AL57). In this case, the fifth vehicle compares the inter-vehicle distance probe trajectory generated through the direct wireless communication with the sixth vehicle, with the inter-vehicle distance reference trajectory already acquired from the management server 204. Thus, without using the radar device, the inter-vehicle distance between the fifth and sixth vehicles can be estimated.

In the on-vehicle apparatus 203 configured as described above, the direct wireless communication device 213 performs direct wireless communication to receive data transmitted from the on-vehicle apparatus 203 of some other vehicle, which transmits data through radio transmission. Then, the received signal strength RSSI of the direct wireless communication device 213 is detected (step S1050).

Further, the RAM 223 stores inter-vehicle distance reference trajectory information. In this information, two or more points are provided to show a relation of the received signal strength RSSI with the relative distance between the on-vehicle apparatus 203 of some other vehicle and the on-vehicle apparatus 203 of the own vehicle. In this case, the received signal strength RSSI shows the strength when the data transmitted from the on-vehicle apparatus 203 of some other vehicle is received by the direct wireless communication device 213 through radio reception.

Further, an inter-vehicle distance (probe inter-vehicle distance) between the own vehicle and the preceding vehicle is calculated with reference to the time point when a radio beacon has initially been detected (step S1060). Then, inter-vehicle distance probe trajectory information is generated, which indicates a relation of a plurality of received signal strengths RSSI of the direct wireless communication device 213, to a plurality of probe inter-vehicle distances (step S1070).

The inter-vehicle distance reference trajectory information is compared with the inter-vehicle distance probe trajectory information to determine a relation between relative distance and probe inter-vehicle distance (step S1100).

Then, an inter-vehicle distance to the on-vehicle apparatus 203 of some other vehicle is determined on the basis of the relation between the inter-vehicle distance reference trajectory information and the inter-vehicle distance probe trajectory information and the currently detected received signal strength RSSI (step S1110).

Thus, the on-vehicle apparatus 203 of the own vehicle, when it moves in the vicinity of the on-vehicle apparatuses 203 of other vehicles, can perform direct wireless communication with one on-vehicle apparatus 203 corresponding to the inter-vehicle distance trajectory information (i.e. the on-vehicle apparatus 203 installed in some other vehicle). Thus, a relative distance between the on-vehicle apparatus 203 of the own vehicle and some other vehicle can be determined.

Inter-vehicle distance reference trajectory information is acquired from the management server 204 by performing wireless communication, via the wide-area wireless communication network NW, with the management server 204 that manages the inter-vehicle distance reference trajectory information (step S1030).

Thus, a necessary piece of inter-vehicle distance reference trajectory information can be acquired from the management server 204, from among a number of pieces of inter-vehicle distance reference trajectory information, which are provided on the basis of combination between the vehicle type of the own vehicle and the vehicle type of a preceding vehicle. Accordingly, the data storage area of the on-vehicle apparatus 203 can be saved.

The on-vehicle apparatus 203 is installed in a vehicle (the own vehicle) that travels on a road. Thus, the own vehicle installs the radar device 215 that measures a relative distance to a vehicle (preceding vehicle) travelling ahead of the own vehicle. The on-vehicle apparatus 203 of the own vehicle generates radar probe trajectory information that indicates a relation between detected received signal strength RSSI and radar inter-vehicle distance measured by the radar device 215 (step S1090).

The on-vehicle apparatus 203 of the own vehicle performs wireless communication via the wide-area wireless commu-

nication network NW to transmit the generated radar probe trajectory information to the management server **204** (step S**1020**). Thus, the management server **204** that manages the inter-vehicle distance reference trajectory information uses the newly acquired radar probe trajectory information to update the inter-vehicle distance reference trajectory information.

In the embodiment described above, the on-vehicle apparatus **203** is the wireless communication apparatus of the present invention. Likewise, the on-vehicle apparatus **203** of some other vehicle is the radio transmitter; the direct wireless communication device **213** is the radio communicating means or unit; step S**1050** is the detecting means or unit; the RAM **223** is the reference information storing means or unit; step S**1060** is the distance measuring means or unit; step S**1070** is the first generating means or unit; step S**1100** is the relation determining means or unit; and step S**1110** is the position determining means or unit

Further, the received signal strength RSSI is the radio reception condition of the present invention. Likewise, the "relative distance between the on-vehicle apparatus **203** of some other vehicle and the on-vehicle apparatus **203** of the own vehicle" is the position related information; the inter-vehicle distance reference trajectory information is the relation reference information (relation reference information); the probe inter-vehicle distance is the relative distance information (relative distance related information); and the inter-vehicle distance probe trajectory information is the first relation information (first relation measurement information).

Furthermore, step S**1030** is the third reference information acquiring means or unit. Likewise, step S**1090** is the second generating means or unit; step S**1020** is the third measurement information transmitting means or unit; the radar device **215** is the relative distance measurement apparatus; the radar probe trajectory information is the second relation information (second relation measurement information); and the management server **204** is the second management apparatus.

Sixth Exemplary Embodiment

Next, a sixth embodiment of the present invention is described with reference to FIGS. **30** and **31**. In the sixth embodiment, only the differences from the first embodiment are described. In the sixth embodiment, the components identical with or similar to those in the first embodiment are given the same reference numerals for the sake of omitting unnecessary explanation.

The wireless positioning system **1** of the sixth embodiment is different from the first embodiment in that there are some changes in the processing steps performed by the reference station **2** and in the steps of the position estimation process. The remaining steps are similar to those of the first embodiment.

Upon reception of the information that indicates the current location of the vehicle (vehicle current location information) from the on-vehicle apparatus **3**, the reference station **2** carries out a step of including the received vehicle current location information into a radio beacon.

Except for this additional step, the remaining steps are similar to those of the first embodiment. In other words, the reference station **2** periodically transmits, to the vehicles around it, the radio beacon that includes the identification information of the reference station **2** and the received vehicle current location information, using the direct wireless communication function.

As shown in FIG. **30**, the position estimation process of the sixth embodiment is similar to that of the first embodiment except that steps S**1310** and S**1320** have been added.

Specifically, when step S**100** is finished, control proceeds to step S**1210**. At step S**1310**, the CPU **21** of the on-vehicle apparatus **3** refers to the vehicle current location information included in the radio beacon that has been detected at step S**40** and the current location of the own vehicle calculated at step S**100** to calculate an inter-vehicle distance between the vehicle corresponding to the vehicle current location information and the own vehicle.

Then, at step S**1320**, the CPU **21** transmits information that indicates the current location of the own vehicle (own vehicle's current location information) calculated at step S**100** to the reference station **2** and then once ends the position estimation process.

Referring to FIG. **31**, hereinafter is described a specific example of the inter-vehicle distance estimation performed in the wireless positioning system **1** configured as described above.

As shown in FIG. **31**, a vehicle installing the on-vehicle apparatus **3***a* (hereinafter referred to as first vehicle) and a vehicle installing the on-vehicle apparatus **3***b* (hereinafter referred to as second vehicle) travel on a road R**6** in the vicinity of the reference station **2***a*.

The first vehicle travels ahead of the second vehicle. Further, the first vehicle travels on a curve of the road R**6**, while the second vehicle travels just before the curve. There is an obstacle on a line connecting between the first and second vehicles (see the broken line DL**61**). In this case, if the second vehicle installs a radar device, it is difficult for the second vehicle to accurately estimate a distance between the first and second vehicles (inter-vehicle distance).

In this situation, however, the first vehicle is able to transmit its own vehicle's current location information to the reference station **2***a* (see the arrow AL**61**) and the reference station **2***a* is able to transmit the own vehicle's current location information of the first vehicle to the second vehicle (see the arrow AL**62**). Thus, the second vehicle is able to accurately estimate the distance between the first and second vehicles.

Further, the second vehicle may transmit its own vehicle's current location information to the reference station **2***a* (see the arrow AL**63**) and the reference station **2***a* may transmit the own vehicle's current location information of the second vehicle to the first vehicle (see the arrow AL**64**). Thus, the first vehicle is able accurately estimate the distance between the first and second vehicles.

The on-vehicle apparatus **3** configured as described transmits the own vehicle's current location information to the reference station **2**, using the direct wireless communication device **13**, the reference station **2** having a function of receiving the own vehicle's current location information through direct wireless communication and a function of transmitting the received own vehicle's current location information through direct wireless communication (step S**1320**). Thus, the on-vehicle apparatus **3** is able to transmit/receive own vehicle's current location information to/from the reference station **2** through direct wireless communication.

Accordingly, the on-vehicle apparatus **3** is able to determine an inter-vehicle distance to another on-vehicle apparatus **3** positioned in the vicinity of the same reference station **2**.

In the embodiment described above, step S**1320** is the position information transmitting means or unit. Likewise,

the own vehicle's current location information is the apparatus current location information.

Seventh Exemplary Embodiment

Next, a seventh exemplary embodiment of the present invention is described with reference to FIG. **32**, focusing on the differences from the third embodiment. In the seventh embodiment, the components identical with or similar to those in the third embodiment are given the same reference numerals for the sake of omitting unnecessary explanation.

As shown in FIG. **32**, the wireless positioning system **101** of the seventh embodiment is different from the third embodiment in that the reference station **102** is set up along an eight-lane (four lanes each way) road R**7**, an obstacle **150** is provided between the reference station **102** and the road R**7**, and the position estimation process has been changed. The remaining configuration is the same as that of the third embodiment.

Due to the presence of the obstacle **150** between the reference station **102** and the road R**7**, a direct wave arrival region A**1**, a diffracted wave arrival region A**2** and a blocked region A**3** are formed above the road R**7**.

The direct wave arrival region A**1** (hereinafter also just referred to as region A**1**) is a region for the arrival of direct waves that are not blocked by the obstacle **150**, among the radio beacons transmitted from the reference station **102**. The reference station **102** transmits the radio beacons via radio waves.

The diffracted wave arrival region A**2** (hereinafter also just referred to as region A**2**) is a region for the arrival of diffracted waves that are diffracted by the obstacle **150**, among the radio beacons transmitted from the reference station **102**.

The blocked region A**3** (hereinafter also just referred to as region A**3**) is a region where neither the direct waves nor the diffracted waves arrive.

The diffracted wave arrival region A**2** is formed on both sides of the blocked region A**3** along the travelling direction on the road R**7**. With respect to the region A**2** formed on each side of the blocked region A**3**, the direct wave arrival region A**1** is formed on the other side of the region A**2**, which is opposite to the side where the blocked region A**3** is formed.

The RAM **123** of the control unit **112** (see FIG. **11**) stores reference trajectory information regarding the reference station **102** that installs the control unit **112**, being classified on the basis of vehicle type and travelling direction of vehicles. Each piece of reference trajectory information includes reference trajectories concerning first to fourth lanes that configure the four lanes on one way (see reference trajectories TR**1**, TR**2**, TR**3** and TR**4** in FIG. **32**).

The reference trajectory TR**1** (TR**2**, TR**3** or TR**4**) indicates that the probe quantity gradually increases as the vehicle travelling on the first (second, third or fourth) lane of the road R**7** approaches the reference station **2**. Then, at the boundary between the region A**1** and the region A**2** on the first (second, third or fourth) lane, the reference trajectory TR**1** bends in a direction of decreasing the probe quantity as the vehicle approaches the reference station **2** (see the bending point Pa**1** (Pa**2**, Pa**3** or Pa**4**) in FIG. **32**).

Further, the reference trajectory TR**1** (TR**2**, TR**3** or TR**4**) indicates that, as the vehicle travels away from the boundary between the regions A**1** and A**2** toward the reference station **2**, the probe quantity gradually decreases. Furthermore, the reference trajectory TR**1** bends at the boundary between the regions A**2** and A**3** on the first (second, third or fourth) lane (bending point Pb**1** (Pb**2**, Pb**3** or Pb**4**) in FIG. **32**) and then indicates that the probe quantity is fixed in the region A**3**.

The position estimation process of the seventh embodiment is the same as that of the third embodiment except that step S**370** has been changed.

Specifically, step S**370** is different from that of the third embodiment in that the CPU **141** of the on-vehicle apparatus **103** determines whether or not a probe trajectory matches a reference trajectory.

More specifically, the CPU **141** sets preferential and normal areas for matching in each of the reference trajectories TR**1**, TR**2**, TR**3** and TR**4** (FIG. **32** shows preferential and normal areas for matching in the reference trajectory TR**1**). The preferential area is set so as to be specific to each of the reference trajectories TR**1**, TR**2**, TR**3** and TR**4**. In this case, the preferential area for matching is set for each of the reference trajectories TR**1**, TR**2**, TR**3** and TR**4** so as to include all of the regions A**2** and A**3**. The normal area for matching is also set so as to be specific to each of the reference trajectories TR**1**, TR**2**, TR**3** and TR**4**. In each of the reference trajectories TR**1**, TR**2**, TR**3** and TR**4**, the normal area for matching corresponds to the area other than the preferential area for matching.

Then, the probe trajectory is superimposed over the reference trajectory, followed by calculating a difference between the probe quantity of the reference trajectory and that of the probe trajectory at a plurality of points on the reference trajectory (hereinafter the difference is referred to as probe quantity difference). Further, the CPU **141** calculates an inverse number for each of the calculated probe quantity differences, followed by multiplying the inverse number with a predetermined weight coefficient.

Then, the CPU **141** calculates an average of the multiplied values at the plurality of points on the reference trajectory to use the average as a degree of matching. The weight coefficient in the preferential area for matching is ensured to be larger than that of the normal area for matching.

The wireless positioning system **101** configured as described above includes the obstacle **150** between the reference station **102** and the road R**7** laid around the reference station **102**. In this case, the obstacle **150** blocks the radio waves propagated from the reference station **102** for transmission of the radio beacons.

Accordingly, the reference trajectory TR**1** (TR**2**, TR**3** and TR**4**) indicates that the probe quantity gradually increases as the vehicle travelling on the first (second, third or fourth) lane of the road R**7** approaches the reference station **2**. Then, at the boundary between the region A**1** and the region A**2** on the first (second, third or fourth) lane, the reference trajectory TR**1** bends in a direction of decreasing the probe quantity as the vehicle approaches the reference station **2** (see bending point Pa**1** (Pa**2**, Pa**3** or Pa**4**) in FIG. **32**). The bending point Pa**1**, Pa**2**, Pa**3** or Pa**4** is generated at the boundary between the regions A**1** and A**2**.

The positions on the road R**7** corresponding to the bending points Pa**1**, Pa**2**, Pa**3** and Pa**4** of the reference trajectories TR**1**, TR**2**, TR**3** and TR**4**, respectively, are unlikely to be affected by the ambient reflection (e.g., reflection of radio waves from the buildings around the reference station **102**) and thus are stable. Specifically, the bending point Pa**1**, Pa**2**, Pa**3** or Pa**4** will have only a small variation in the position in the travelling direction of the vehicle on the road R**7** and in the direction perpendicular to the travelling direction (i.e. in the direction from the first lane toward the fourth lane). Also, the bending point Pa**1**, Pa**2**, Pa**3** or Pa**4** will have only a small variation attributed to the difference in the vehicle type.

This is because the probe quantity of the direct waves becomes larger than the ambient reflection owing to the fact that the reference station **102** is set up near the road R**7**, and

because the bending points are originated from the direct waves having such a large probe quantity.

Thus, when bending points are generated in a generated probe trajectory, the on-vehicle apparatus **103** superimposes the bending points on the probe trajectory over those generated on the reference trajectory TR**1**, TR**2**, TR**3** or TR**4** to accurately estimate the current location in the on-vehicle apparatus **103** and the lane of the road R**7**, on which the vehicle that installs the on-vehicle apparatus **103** (own vehicle) travels.

For example, the probe trajectory shown in FIG. **32** matches the reference trajectory TR**1** at the bending point Pa**1**. Accordingly, the vehicle that installs the on-vehicle apparatus **103** is estimated to travel on the first lane.

In the comparison between the reference trajectory information and the probe trajectory information, the on-vehicle apparatus **103** determines a relation between reference travel distance and probe travel distance, using the results of the comparison performed when the position on the road R**7** in the reference trajectory information is included in the preferential area for matching, in preference to the results of the comparison performed when the position is not included in the preferential area for matching (step S**370**).

Accordingly, the estimation of the current location of the on-vehicle apparatus **103** and the driving lane is hardly affected by the results of comparison performed in the normal area for matching that has lower accuracy in the estimation of these data than in the preferential area for matching. Thus, the estimation accuracy of the current location of the on-vehicle apparatus **103** and the driving lane is maintained.

Further, since the reference station **102** transmits the radio beacon via radio waves, the on-vehicle apparatus **103** is unlikely to be affected by the weather in detecting the probe quantity of the radio beacon.

Also, the on-vehicle apparatus **103** calculates inverse numbers of the probe quantity differences at a plurality of points on the reference trajectory TR**1**, TR**2**, TR**3** or TR**4**, as parameters that indicate a degree of matching between the probe quantities of the reference trajectory TR**1**, TR**2**, TR**3** or TR**4** and the probe quantities of the probe trajectory.

At the same time, the on-vehicle apparatus **103** multiplies each of the inverse numbers of the probe quantity differences calculated at the plurality of points on the reference trajectory TR**1**, TR**2**, TR**3** or TR**4** with a weight coefficient that is predetermined on the basis of the corresponding point on the reference trajectory.

Then, using the plurality of multiplied values, the on-vehicle apparatus **103** determines the relation between reference travel distance and probe travel distance.

Further, the weight coefficient in the case where the points on the reference trajectory TR**1**, TR**2**, TR**3** or TR**4** are included in the preferential area for matching is ensured to be larger than the weight coefficient in the case where the points are not included in the preferential area for matching.

Thus, with such a simple method of changing the weight coefficient between the preferential area for matching and areas other than this, the comparison results in the case where the points are included in the preferential area for matching can be used in preference to the comparison results in the case where the points are not included in the preferential area for matching.

In the exemplary embodiment described above, the diffracted wave arrival region A**2** and the blocked region A**3** are the direct wave non-arrival region of the present invention. Likewise, the preferential area for matching is the preferential area; and the inverse number of a probe quantity difference is the parameter that indicates a degree of matching.

Various embodiments of the present invention have been described so far. However, the present is not limited to these embodiments but may be modified in various manners as far as the modifications fall within a technical scope of the present invention.

For example, in the above embodiments, the received signal strength RSSI is used as a probe quantity. Alternative to this, TOF (time of flight) or incoming angle of a radio wave may be used as a probe quantity.

In the above embodiments, reference trajectory information is provided for each vehicle type. Alternative to this, reference trajectory information may be provided for each type of direct wireless communication device installed in the on-vehicle apparatus.

In the above embodiments, a reference trajectory is updated by determining whether the probe trajectory is of the first lane or of the second lane on the basis of speed information and steering angle information. Alternative to this, when the statistics of probe trajectory converge on a plurality of trajectories, the converged trajectories may be registered as being the reference trajectories of the respective lanes.

In the above embodiments, an average of probe trajectories is calculated for the probe trajectories of each classification and the average value is used as a reference trajectory. Alternative to this, a reference trajectory may be derived as a trajectory that maximizes the statistical indicator of a degree of similarity, with respect to a group of probe trajectories received in the past.

In the seventh exemplary embodiment, the obstacle **150** is provided between the reference station **102** and the road R**7**. However, as shown in FIG. **33**, in an indoor site (e.g., indoor parking area) where a structure such as of ferroconcrete having high blocking properties is built, the reference station **102** may be provided so that the structure (the post **160** in FIG. **33**) is located between the reference station **102** and a region where positioning is performed.

In an indoor environment that causes lots of reflections, the received signal strength RSSI is greatly influenced by the vehicles around there, causing large variation in a probe trajectory (refer to the arrow AR**71** in FIG. **33**). However, when a region for blocking direct waves is provided in a region where decay of the direct waves from the reference station **102** is small (a region near the reference station **102**), the characteristic points (refer to the bending points Pc**1** and Pc**2** in FIG. **33**) can be extracted with a contrast higher than the environmental factors.

In the seventh exemplary embodiment, the obstacle **150** is provided being distanced from the reference station **102**. In setting up the reference station **102** and the obstacle **150**, the reference station **102** may be set up first and then the obstacle **150** may be set up so as to be located between the reference station **102** and the road. Alternatively, when the obstacle **150** is already set up near the road before setting up the reference station **102**, the reference station **102** may be set up so that the obstacle **150** is located between the reference station **102** and the road.

Further, as shown in FIG. **34**, the obstacle **150** may be replaced by a blocking plate **170**. The blocking plate **170** may be connected to the reference station **102** so as to be located between the reference station **102** and the road R**7**. Thus, the reference station **102** and the obstacle are integrated.

In this way, the positional relationship between the reference station **102** and the obstacle is fixed to thereby suppress variation in the positions of the bending points in the reference trajectory TR**1**, TR**2**, TR**3** or TR**4**. As a result, the accuracy is enhanced in the estimation of the current location of the on-vehicle apparatus **103** and the travelling lane.

In the seventh exemplary embodiment, radio beacons are transmitted via radio waves. Alternative to this, radio beacons may be transmitted via optical waves. Since optical waves have higher straightness than radio waves, the influence of the ambient reflections can be further mitigated. However, optical waves are likely to be influenced by weather. In order to avoid the influence of weather as much as possible, radio beacons may be transmitted via sonic waves.

In the seventh exemplary embodiment, the reference trajectories TR**1**, TR**2**, TR**3** and TR**4** are each superimposed over a probe trajectory to determine which one of the reference trajectories TR**1**, TR**2**, TR**3** and TR**4** the probe trajectory matches. Alternative to this, a path that the vehicle travels between the lanes may be estimated on the basis of the reference trajectories TR**1**, TR**2**, TR**3** and TR**4**.

For example, as shown in FIG. **35**, a vehicle that installs the on-vehicle apparatus **103** may move from the fourth lane to the first lane (refer to the arrow AR**81** in FIG. **35**). In this case, first, since the bending point on the probe trajectory matches the bending point Pa**4** of the reference trajectory TR**4**, the position on the fourth lane of the vehicle that installs the on-vehicle apparatus **103** may be estimated. After that, comparing the probe quantity of the probe trajectory with the probe quantities of the reference trajectories TR**1**, TR**2**, TR**3** and TR**4**, the path of movement from the fourth to first lanes can be estimated.

In the seventh embodiment, the weight coefficient in the case where the points on the reference trajectory TR**1**, TR**2**, TR**3** or TR**4** are included in the preferential area for matching is ensured to be larger than the weight coefficient in the case where the points are not included in the preferential area for matching. Alternative to this, the weight coefficient may be determined according the distance between the preferential area for matching and the current location of the vehicle. For example, the weight coefficient may be ensured to become smaller as this distance becomes longer.

In the seventh embodiment, a probe trajectory is compared with a reference trajectory using the inverse numbers of the probe quantity differences. Alternative to this, a probe trajectory may be compared with a reference trajectory using the distance between two bending points generated in the probe trajectory and the distance between two bending points generated in the reference trajectory (Refer to the arrow AR**91** in FIG. **32**. The arrow AR**91** indicates the distance between the two bending points Pa**1** on the reference trajectory TR**1**).

For example, in FIG. **32**, the distance between the two bending points generated in the probe trajectory equals to the distance between the two bending points Pa**1** on the reference trajectory TR**1**. Therefore, the vehicle that installs the on-vehicle apparatus **103** can be estimated to be travelling on the first lane.

While the invention has been particularly shown and described with reference to exemplary embodiments and modifications thereof, the invention is not limited to these embodiments and modifications. It will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope of the present invention as defined by the claims.

What is claimed is:

1. A wireless communication apparatus, comprising:

a wireless communicating unit that receives data transmitted from at least one wireless transmitter by direct wireless communication, the at least one wireless transmitter transmitting data in a wireless manner;

a detecting unit that detects a wireless reception condition in the wireless communicating unit;

a reference information storing unit that stores relation reference information that sets two or more relations between (i) the wireless reception condition in the wireless communicating unit on a reception of data transmitted from the wireless transmitter and (ii) location information relating to a location of the wireless transmitter;

a distance measuring unit that measures relative distance information relating to a relative distance between the wireless transmitter and the wireless communication apparatus:

a first generating unit that generates first relation information indicating a relation between a plurality of the wireless reception conditions detected by the detecting unit and a plurality of the relative distance information measured by the distance measuring unit;

a relation determining unit that determines a relation between the location information and the relative distance information by comparing the relation reference information and the first relation information; and

a position determining unit that determines a current location of the wireless communication apparatus on the basis of (a) the relation between the location information and the relative distance information determined by the relation determining unit and (b) a current wireless reception condition in the wireless communicating unit detected by the detecting unit.

2. The wireless communication apparatus according to claim **1**, wherein:

the wireless transmitter is provided to be fixed to a predetermined installation position;

the location information in the relation reference information is information indicating a position on a road laid around the wireless transmitter; and

the relative distance information in the first relation information is a travel distance of a vehicle provided with the wireless communication apparatus that moves on the road laid around the wireless transmitter.

3. The wireless communication apparatus according to claim **2**, wherein:

the relation reference information is set for each type of the vehicle.

4. The wireless communication apparatus according to claim **3**, wherein:

the road has a plurality of lanes each way; and

the relation reference information is set for each lane of the road.

5. The wireless communication apparatus according to claim **4**, further comprising:

a first reference information acquiring unit that acquires the relation reference information transmitted from the wireless transmitter by using the wireless communication unit.

6. The wireless communication apparatus according to claim **5**, further comprising:

a first measurement information transmitting unit that transmits the first relation information generated in the first generating unit to the wireless transmitter by using the wireless communication unit.

7. The wireless communication apparatus according to claim **6**, further comprising:

a second reference information acquiring unit that acquires the relation reference information transmitted from a first management apparatus that is provided for each wireless transmitter to manage the relation reference information, by performing wireless communication with the first management apparatus via a wide-area wireless communication network.

8. The wireless communication apparatus according to claim 7, further comprising:

a second measurement information transmitting unit that transmits the first relation information generated in the first generating unit to the first management apparatus by performing wireless communication via the wide-area wireless communication network.

9. The wireless communication apparatus according to claim 8, further comprising:

a movement trajectory transmitting unit that transmits movement trajectory information indicating a movement trajectory of the wireless communication apparatus to the first management arrangement by performing wireless communication via the wide-area wireless communication network.

10. The wireless communication apparatus according to claim 9, wherein:

the wireless transmitter includes a receiving function for receiving current location information indicating a current location of the wireless communication apparatus by direct wireless communication, and a transmitting function for transmitting the received current location information by direct wireless communication; and

the wireless communication apparatus further comprises

a location information transmitting unit that transmits the current location information to the wireless transmitter.

11. The wireless communication apparatus according to claim 2, wherein:

an obstacle is located between the wireless transmitter and a road laid around the wireless transmitter, the obstacle blocking a part of waves propagated from the wireless transmitter so as to transmit data; and

the relation determining unit is configured to determine the relation by using a first comparison result in preference to a second comparison result in a comparison between the first relation reference information and the relation information,

the first comparison result being a result of the comparison that is performed in a case where the location information in the relation reference information is included in a preferential area that is set in advance so as to include a boundary between a direct wave arrival region and a direct wave non-arrival region, where the direct wave arrival region is a region on the road at which direct waves arrive and the direct wave non-arrival region is a region on the road at which the direct waves do not arrive, the direct waves being the waves that arrive at the road from the wireless transmitter without being blocked by the obstacle, and

the second comparison result being a result of the comparison that is performed in a case where the location information in the relation reference information is not included in the preferential area.

12. The wireless communication apparatus according to claim 11, wherein:

the obstacle is provided to be fixed to the wireless transmitter.

13. The wireless communication apparatus according to claim 11, wherein:

the waves are radio waves.

14. The wireless communication apparatus according to claim 11, wherein:

the waves are light waves.

15. The wireless communication apparatus according to claim 11, wherein:

the waves are sound waves.

16. The wireless communication apparatus according to claim 11, wherein:

the relation determining unit is configured to:

calculate a parameter that indicates a degree of matching between the wireless reception condition in the relation reference information and the wireless reception condition in the first relation information at a plurality of calculation positions indicated by the location information in the relation reference information;

calculate a multiplied value by multiplying the parameter calculated for each calculation position with a weight coefficient that is predetermined based on the corresponding calculation position and is set in such a manner that a first weight coefficient is larger than a second weight coefficient, where the first weight coefficient is a weight coefficient in a case where the calculation position is included in the preferential area for matching, and the second weight coefficient is a weight coefficient in a case where the calculation position is not included in the preferential area for matching; and

determine the relation by using the calculated multiplied value.

17. The wireless communication apparatus according to claim 1, wherein:

the wireless transmitter is mounted in a first moving object that moves on a road;

the location information in the relation reference information is information indicating a relative distance between the first moving object and the wireless communication apparatus; and

the relative distance information in the first relation information is information indicating an increase and decrease in a relative distance between the first moving object and the wireless communication apparatus with respect to a reference relative distance that is a relative distance between the first moving object and the wireless communication apparatus at a predetermined time point.

18. The wireless communication apparatus according to claim 17, further comprising:

a third reference information acquiring unit that acquires the relation reference information transmitted from a second management apparatus that manages the relation reference information, by performing wireless communication with the second management apparatus via a wide-area wireless communication network.

19. The wireless communication apparatus according to claim 18, wherein:

the wireless communication apparatus is mounted in a second moving object that moves on a road;

the second moving object is provided with a relative distance measurement apparatus that measures a relative distance to the first moving object traveling ahead of the second moving object; and

the wireless communication apparatus further comprises:

a second generating unit that generates a relation between the wireless reception condition detected by the detecting unit and information indicating the relative distance measured by the relative distance measuring apparatus; and

a third measurement information transmitting unit that transmits the second relation information generated in the second generating unit to the second management

apparatus by performing wireless communication via the wide-area wireless communication network.

20. A wireless positioning system, comprising:

at least one wireless transmitter that transmits data in a wireless manner; and

a wireless communication apparatus, including:

a wireless communicating unit that receives data transmitted from the at least one wireless transmitter by direct wireless communication;

a detecting unit that detects a wireless reception condition in the wireless communicating unit;

a reference information storing unit that stores relation reference information that sets two or more relations between (i) the wireless reception condition in the wireless communicating unit on a reception of data transmitted from the wireless transmitter and (ii) location information relating to a location of the wireless transmitter;

a distance measuring unit that measures relative distance information relating to a relative distance between the wireless transmitter and the wireless communication apparatus:

a first generating unit that generates first relation information indicating a relation between a plurality of the wireless reception conditions detected by the detecting unit and a plurality of the relative distance information measured by the distance measuring unit;

a relation determining unit that determines a relation between the location information and the relative distance information by comparing the relation reference information and the first relation information; and

a position determining unit that determines a current location of the wireless communication apparatus on the basis of (a) the relation between the location information and the relative distance information determined by the relation determining unit and (b) a current wireless reception condition in the wireless communicating unit detected by the detecting unit.

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